JPRS 70135

10 November 1977

USSR

SPACE BIOLOGY AND AEROSPACE MEDICINE

No. 5, 1977

U. S. JOINT PUBLICATIONS RESEARCH SERVICE

NOTE

JPRS publications contain information primarily from foreign newspapers, periodicals and books, but also from news agency transmissions and broadcasts. Materials from foreign-language sources are translated; those from English-language sources are transcribed or reprinted, with the original phrasing and other characteristics retained.

Headlines, editorial reports, and material enclosed in brackets [] are supplied by JPRS. Processing indicators such as [Text] or [Excerpt] in the first line of each item, or following the last line of a brief, indicate how the original information was processed. Where no processing indicator is given, the information was summarized or extracted.

Unfamiliar names rendered phonetically or transliterated are enclosed in parentheses. Words or names preceded by a question mark and enclosed in parentheses were not clear in the original but have been supplied as appropriate in context. Other unattribute parenthetical notes within the body of an item originate with the source. Times within items are as given by source.

The contents of this publication in no way represent the policies, views or attitudes of the U.S. Government.

PROCUREMENT OF PUBLICATIONS

JPRS publications may be ordered from the National Technical Information Service (NTIS), Springfield, Virginia 22151. In ordering, it is recommended that the JPRS number, title, date and author, if applicable, of publication be cited.

Current JPRS publications are announced in Government Reports Announcements issued semimonthly by the NTIS, and are listed in the Monthly Catalog of U.S. Government Publications issued by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

Indexes to this report (by keyword, author, personal names, title and series) are available through Bell & Howell, Old Mansfield Road, Wooster, Ohio, 44691.

Correspondence pertaining to matters other than procurement may be addressed to Joint Publications Research Service, 1000 North Glebe Road, Arlington, Virginia 22201.

JPRS 70135

10 November 1977

SPACE BIOLOGY AND AEROSPACE MEDICINE

No. 5, 1977

Complete translation of the Russian-language periodical KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA published in Moscow by the Meditsina Izdatel'stvo

CONTENTS

CONTENTS (Continued) Page

PUBLICATION DATA

English title	:	SPACE BIOLOGY AND AEROSPACE MEDICINE No. 5, 1977
Russian title	:	KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA
Author (s)	:	
Editor (s)	:	O. G. Gazenko
Publishing House	:	Meditsina
Place of Publication	:	Moscow
Date of Publication	:	1977
Signed to press	:	12 August 1977
Copies	:	1705
COPYRIGHT	:	Kosmicheskaya biologiya i Aviakosmicheskaya meditsina

SIXTIETH ANNIVERSARY OF THE GREAT OCTOBER REVOLUTION

UDC: 574.68+613.693

MAIN STAGES AND PROSPECTS OF DEVELOPMENT OF SPACE BIOLOGY AND MEDICINE

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian
No 5, 1977 pp 3-12

[Article by A. I. Burnazyan, Ye. I. Vorob'yev, O. G. Gazenko, N. N. Gurovskiy, Yu. G. Nefedov, B. A. Adamovich, B. B. Yegorov, Ye. Ye. Kovalev and A. D. Yegorov, submitted 25 Apr 77]

[Text] The beginning of the second half of the 20th century was marked by in-depth theoretical research in cosmonautics, as well as practical development of high-power space rocket systems that made it possible to implement the first manned space flight. Work in the field of cosmonautics was substantially stimulated by the development of many sciences, including space biology and medicine.

Space biology is a branch of biology that deals primarily with three main problems: 1) distinctions of vital functions and behavior of terrestrial organisms in space or during flights (extraterrestrial life of terrestrial organisms--ecophysiology); 2) detection of living matter in the universe, including that originating in planets other than earth, and investigation of its distinctive features and evolution (exobiology); 3) principles and methods of creating an artificial environment in spacecraft and space stations (biotechnology, ecology of closed systems).

Space medicine emerged because of the requirements of cosmonautics, and it accumulated the advances of physiology, hygiene and medicine.

The main objectives of space medicine are: providing for vital functions and safeguarding the health of cosmonauts at all stages of space flights and after them; development of methods of screening and training cosmonauts; development of recommendations for maintaining high efficiency of cosmonauts during space flights, extravehicular activity and on other planets; investigation of the effects of space flight conditions on the human body; development of preventive measures, protective gear and methods of treating adverse phenomena related to weightlessness and the effects of other space flight factors on the organism.

One can arbitrarily single out three main stages of development of space biology and medicine:

First stage--preparations for manned space flights; this stage covered a significant period of time and included the following objectives: generalization of data in aviation medicine and physiology accumulated in the study of the effects of deleterious environmental factors on the animal and human organism; laboratory research involving simulation of the effects of the main factors of space flights on the organism; experiments on animals involving flights in rockets and satellites; problems of nutrition, water and oxygen supply, waste utilization, etc.; clinicophysiological problems (screening and training of crews, methods of disease prevention, methods of rendering medical care in the case of development of disease, etc.); psychophysiological problems (psychological compatibility, work and rest schedule); methods of preventing the adverse effects of flight factors on the crew in order to assure a high degree of efficiency.

One of the chief problems, without the solution of which a space flight would be impossible, is to develop systems to provide optimum atmosphere, temperature, nutrition and water for cosmonauts and for removal of products of vital functions.

Depending on the methods used for regeneration of oxygen and removal of carbon dioxide, water vapor and toxic admixtures, life support systems can be based on physical, physicochemical and biological principles. Physical and physicochemical methods are based on the use of oxygen reserve taken from earth, or oxygen obtained from carbon dioxide and water. Excretion products are absorbed as a result of physicochemical processes, for example, sorption, condensation, dilution, etc. Biological methods are based on the principle of the cycle of elements, in the course of which oxygen is formed from carbon dioxide in photosynthesis of plants. Open life support systems, based on supplies taken from earth, were used in the vertical launching of rockets, biosatellite flights with animals on board, as well as manned flights. Partially closed life support systems require the use of a certain share of products of man's vital functions for regeneration of required substances. Closed systems are characterized by a virtually complete cycle of elements and do not require replenishment with supplies taken on earth. However, in such systems, the energy source is external and is not contained in the closed circuit. Biological equivalence to earth's normal atmosphere is a mandatory requirement of the atmosphere of inhabited modules. An artificial gas atmosphere is used in Soviet spacecraft, which is close to earth's atmosphere in pressure and gas composition. Such a gas environment is the most adequate for man in the case of long-term exposure, since he adapted to it in the course of evolution. Future research in this field should direct itself to the choice of optimum correlations between the main parameters, determination of maximum permissible parameters of the environment and toxic admixtures for various flights and development of new, more effective means of supplying the gas ingredients.

Provisions for extravehicular activity of man in space and on other planets are an important medicotechnological problem; they could be supplied, in particular, in the form of personal gear (space suits with autonomous life support system, device for aiding in movement, etc.). In developing the

medical specifications for space suits, consideration is given not only to the need to maintain microclimate and temperature parameters at the proper level, but design features that would make possible movement and work in space.

The problem of nutrition and water supply for crews is presently being solved on the basis of using food and water taken from earth. In addition, systems of water regeneration from products of vital functions and, in particular, from the moisture exhaled by man, are being used more recently.

The problem of producing food and water onboard a spacecraft can be resolved by creating a cycle of elements on the basis of physicochemical or biological methods. Physicochemical methods of food regeneration are based on conversion of products of man's metabolism and excretion into food substances. At the present time, studies are in progress of the possibility of synthesizing compounds such as amino acids, fatty acids and glucose. A partially or completely closed cycle of elements based on biological methods provides for the use of a number of biological objects onboard the spacecraft: higher and lower plants, some representatives of heterotrophic organisms, etc. Work in this direction is still at the first stage of development, and biological synthesis systems are a matter of the future. At the present time, physicochemical methods have been tested in ground-based experiments for regeneration of oxygen and water. In 1967-1969, in the USSR, a year-long medicotechnical experiment was conducted sith three subjects; in it, electrochemical and catalytic methods were used to regenerate oxygen and water from the products of man's vital functions.

Future development of problems of nutrition and water supply during space flights includes the study of energy and plastic requirements of the organism, providing the organism with minerals, vitamins and the main food ingredients, and satisfying individual tastes. In long-term flights, preference should be given to the ordinary and natural products and dishes consumed on earth. In view of the fact that the main problems of nutrition can be resolved only through studies during space flights, it is imperative to refine and develop new equipment for quantitative assay of intake of water and food, as a whole and of the main ingredients, including minerals, as well as the waste excreted from the organism. Finally, extensive studies must be pursued for theoretical and practical development of problems of regeneration of food and water on the basis of the cycle of elements.

The problem of screening individuals that are physically fit for space flights emerged already when Yu. A. Gagarin was being prepared for the first manned flight. In essence, this problem consists of predicting endurance of the conditions involved in a proposed space flight, with retention of adequate efficiency to perform the flight program. Even at the earliest stages, there are a number of specific distinctions to cosmonaut screening; however, it was based on the knowhow of medical flight expertise used in aviation. The development of cosmonautics and appearance of spacecraft that can accommodate many crew members made it necessary to include in the crew not only pilots, but engineers involved with development of this

technology (experimenter cosmonauts) and scientists (investigator cosmonauts). Knowhow in space flights was also acquired, and knowledge about the effects of space flight factors on the organism expanded. All this led to distinction of the problem of cosmonaut screening as an independent discipline. The chief principle of screening is the continuity of this process, starting with the first meeting with a candidate and ending with permission for him to fly at the space port. The system of medical screening presently adopted is undergoing dynamic development, accumulating the current advances of clinical and space medicine.

In planning medical support of long-term flights, one must bear in mind the possibility that crew members may become sick during such flights. And it is quite apparent that the probability of sickness will increase with increase in duration of space flights. Hence, there is the problem of developing ways and means of diagnostics and rendering medical and preventive care, including emergency care.

Development of the "man--machine" problem is acquiring importance in the field of space psychophysiology.

In the "man--spacecraft" system, man played a relatively minor role in the first few space flights. At the present time, the crew performs some rather important operations with regard to piloting and experimentation, as well as monitoring the operation of systems.

Some degree of comfort and conveniences during flights is a mandatory prerequisite for maintaining a high degree of crew efficiency. In the course of developing programs of manned space flights, conditions of vital functions were constantly refined. With increase in duration of flights and number of cosmonauts constituting the crew, problems of creating optimum working and living conditions onboard spacecraft are gaining even more importance. The above-mentioned problems are quite multifaceted, and maintaining efficiency and emotional tonus of cosmonauts depends, to some extent, on the successful solution thereof. We shall discuss here only some aspects of these problems.

Studies conducted during flights revealed that efficiency is largely determined by rational planning of the "wakefulness-sleep" cycle. A shorter or longer daily cycle requires some tension of regulatory systems and time for the organism to adopt a new circadian rhythm. Given the possibility of some changes during flights, in the direction of longer or shorter cycles, one should still aim at a 24-hour cycle, which is apparently the most adequate for long-term space flights.

Organization of rest for the crew is important in long flights. In this respect, studies must be pursued for substantiation of the approach to stocking onboard libraries, selecting tapes and videotapes, movies and other means of supplying information to the crew.

Medical monitoring plays a significant role in the set of measures that assure the safety of space flights and provide information about the condition of vital systems of the organism.

The objective of medical monitoring is to evaluate and predict the physical condition of crew members, as well as to issue recommendations for preventive and therapeutic measures during a flight. The ultimate goal of medical monitoring is to assure safe flights and safeguard the health of cosmonauts.

Development of a scientifically substantiated diagnostic system in space flights includes the following stages: determination of the most probable adverse conditions and diseases; choice of a set of physiological parameters, as well as the most informative functional tests required and sufficient for evaluation and prediction of physical condition of crew members during flights; development of methods of obtaining, analyzing, storing and displaying medical information during flights.

During the first few flights, medical indices (EKG, respiration rate) were recorded in all "receiving" orbits, and 1-2 times a day starting with the flight of Soyuz-9.

During the flights of the orbital stations, in addition to a system of operational medical monitoring, there was a system of period examinations (about once a week) that included recording of arterial pressure by the tachyoscillographic method, phase structure of the cardiac cycle (kinetocardiogram and sphygmogram), pulse wave distribution rate (sphygmogram of various parts of the body), venous pressure (phlebographic method), EKG in 12 leads, with the use of functional tests and at rest. The functional tests included measured physical loads on a bicycle ergometer, and application of negative pressure to the lower part of the body.

Generalization of the results of medical monitoring and examinations in flight revealed that space flight conditions lead to development of specific phenomena in a number of instances, including the following: a set of symptoms resembling seasickness; a change in functional state of the cardiovascular system in the form of decreased orthostatic stability and endurance of physical loads; change in fluid and electrolyte metabolism in the form of a decrease in circulating blood volume and change in electrolyte content of body fluids; decreased mineralization of bone tissue; the anemic syndrome in the form of decreased erythrocyte mass, thrombocytes and decreased resistance of erythrocytes; change in immunological reactivity with decline of some indices of natural immunity.

The severity of these signs is quite variable and depends largely on individual distinctions of the organism. Occurrence of such phenomena stimulated development and implementation of measures directed toward decreasing redistribution of blood, stimulation of neuroreflex mechanisms that regulate hemodynamics in vertical position of the body; physical loads to maintain the conditioning of the most important systems of the organism and stimulation of some groups of receptors (physical exercises and training, weighted suits, load applied to skeleton); purposeful administration of drugs; addition to food of salts, protein and vitamins that regulate fluid and electrolyte metabolism, setting norms for nutrition and water intake.

With regard to further investigation of phenomenology and mechanisms of changes in physiological functions during space flights, there are a number of problems to be solved: determination of the role and share of redistribution of blood, change in hydration observed in flight, as well as development of methods of forecasting and preventing these disorders; comprehensive studies of the myocardium, venous circulation, renal hemodynamics, the role of a possible calcium deficiency and changes in calcium balance; investigation of erythropoiesis, etc.

Analysis of the effects of prolonged weightlessness on elementary processes of vital functions, investigation of the mechanisms of adaptation of various physiological systems to prolonged weightlessness and readaptation to earth's gravity, as well as investigation of the combined effect on the organism of weightlessness and cosmic radiation were performed in flight experiments with animals and plant objects onboard various space craft, and in particular on the biosatellites Kosmos-110 (22 Feb--11 Mar 66), Kosmos-368 (8 Oct--14 Oct 70), Kosmos-605 (31 Oct--22 Nov 73), Kosmos-690 (22 Oct--12 Nov 74) and Kosmos-782 (25 Nov--15 Dec 75).

The numerous experiments conducted on biosatellites of the Kosmos series on microorganisms, animal and plant tissue cultures, higher and lower plants, insects, fish, some reptiles and other biological objects failed to demonstrate a deleterious effect of prolonged weightlessness on intracellular biological processes, including those related to transmission of genetic information and occurrence of successive cell divisions.

Comprehensive investigation of the main physiological systems of the animal organism during biosatellite flights failed to demonstrate pathological effects due to weightlessness. At the same time, some reliable data were obtained to the effect that there are changes in a number of tissues and organs under the influence of weightlessness. The most significant structural changes were demonstrated in the thymus, lymph nodes and spleen, which are organs whose function, as we know, is closely related to protection of the organism against microorganisms, as well as in the endocrine glands involved in adaptation of the organism to altering environmental factors and musculoskeletal system.

For the time being, it is difficult to assess the potential consequences of the above changes. However, it should be noted that the structural and functional changes essentially disappeared 25 days after 3-week space flights.

These findings, along with the results of examining cosmonauts, lead us to expect that prolonged weightlessness will not lead to the appearance of any specific diseases or death of the organism.

The results of the research with animals also confirmed the scientific substantiation and practical desirability of the system of preventive measures currently used in manned space flights.

For the first time in cosmonautic practice, experimental studies with artificial gravity were pursued during the flight of the Kosmos-782 biosatellite. For this purpose, a centrifuge was installed on the biosatellite and biological objects were placed in the centrifuge.

Studies conducted with the onboard centrifuge established that the biological effect of artificial gravity during a space flight is basically the same as the effect of earth's gravitation. Thus, it was experimentally demonstrated, for the first time, that it is possible to make effective use of an onboard centrifuge on a spacecraft for the prevention of the undesirable effects of prolonged weightlessness.

In the studies pursued on biosatellites of the Kosmos series, much attention was also devoted to the question of radiation safety of long-term space flights. It was of particular interest to investigate the combined effect of prolonged weightlessness and ionizing radiation. This was due to the need to assess radiation safety in a real space flight and to obtain, on this basis, the necessary data for substantiation of permissible levels of radiation to which spacecraft crews could be exposed and planning of radioprotection.

For this reason, an artificial source of radiation, from ^{137}Cs, was installed onboard the Kosmos-690 biosatellite, which made it possible to simulate the potential exposure of cosmonauts in the case of a powerful solar burst in the course of long-term weightlessness.

Postflight examination of animals revealed that exposure to radiation during the flight, under weightless conditions, had no appreciable effect on radiosensitivity, survival and incidence of genetic changes, as compared to the results of irradiating them in land-based laboratories. In other words, the biological effectiveness of γ-radiation in weightlessness was virtually the same as on earth.

The results of these studies were used for development and substantiation of time standards for radiation safety of cosmonauts involved in flights lasting up to 1 year.

Investigations dealing with electrostatic radioprotection resulted in experimental demonstration, for the first time, of the possibility of creating and maintaining electric fields during long-term space flights, that would be adequate for protection against cosmic radiations, with the use of the vacuum of space as the insulating medium.

Thus, these flights demonstrated the potential of the method of electrostatic protection of a spacecraft against ionizing radiation.

The results of studies obtained in the course of development of electric fields in space have been proposed for use in several branches of the national economy, and in particular for radical upgrading of operating features and reliability of various high-voltage vacuum devices.

Thus, the experimental research pursued during flights of the Kosmos series biosatellites has now made it possible to solve a number of basic problems of space biology and medicine and thereby made a substantial contribution to establishment of the bases and principles of biomedical support of long-term manned space flights.

The advances in space medicine helped solve some problems of medical science as a whole. For example, research and determination of permissible fluctuations of physiological indices in the presence of various loads augmented significantly our knowledge of the range of normal and pathological and, consequently, enriched clinical medicine. Expert methods were refined for intramural work-up of cosmonaut candidates, with regard to those used for screening of aircraft pilots; several new methods have been developed for detection of discrete pathology; some new expert approaches have been substantiated for evaluation of a man's health status. At the present time, many of these methods are already in use in clinical practice in certification of pilots. They include methods of examining the vestibular analyzer, modified hypoxic tests that help detect latent coronary insufficiency, etc.

Standards referable to several parameters of man's environment have been formulated and adopted in wide practice as a result of special research conducted to substantiated life support systems of spacecraft; a toxicological evaluation has been made of a considerable number of new polymers; several works have been performed that were directly related to hygienic practice in the broad sense of the word.

Space medicine has adequate knowhow in the use of miniaturized medical equipment that is resistant to exogenous factors for continuous remote monitoring of man's condition, as confirmed by the use of biotelemetry systems during space flights.

At the present time, reliable methods have been developed for recording and transmitting, by means of telemetry systems, such physiological parameters as the EKG, EEG, blood pressure, seismocardiogram, kinetocardiogram, sphygmogram, EOG, galvanic skin reflex and many others.

The idea of continuous remote medical monitoring, first realized during space flights, found practical applications in several branches of medicine.

Space medicine stimulated numerous investigations of the effect on the organism of hypokinesia, i.e., diminished motor activity. As we know, hypokinesia is very important as an etiological factor in onset of a number of diseases, mainly referable to the cardiovascular system.

Research on the effects of diminished motor activity on the human body revealed the social significance of this problem, on the one hand, and the fact that such a widespread and tested method of therapy as strict bed rest is by no means an indifferent procedure and requires critical interpretation, on the other hand.

Thus, space medicine, a science that is called upon to ensure the safety and success of manned space flights, gave impetus to development of several branches of general medicine; it did not become self-contained, but continues to develop in direct contact with clinical medicine, enriching it with its new developments.

At the present time, a number of problems of space medicine are being resolved within the framework of several international programs. Thus, there is extensive cooperation with several socialist countries, France and the United States with regard to research on biosatellites.

Joint biomedical experiments were performed in the course of the experimental Soviet-American flight of Soyuz--Apollo. These are only examples of the mutually advantageous collaboration with foreign scientists, which is now developing rapidly and aiding in solving the key problems of space medicine.

The specialists in this relatively new branch of science, space biology and medicine, are celebrating the 60th anniversary of Soviet power in an atmosphere of a great creative enthusiasm, with constant refinement of the ways and means of biomedical support of long-term manned space flights. The advances of space biology and medicine are being successfully adopted in "terrestrial" practice and, no doubt, will aid in further development of public health care, industry, agriculture and other areas of human endeavor.

UDC: 613.693(091)(47+57)

AVIATION MEDICINE ON THE SIXTIETH ANNIVERSARY OF THE GREAT OCTOBER REVOLUTION

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian
No 5, 1977 pp 12-18

[Article by N. M. Rudnyy, submitted 31 May 77]

[Text] The Great October Socialist Revolution opened the way for development of creative activity of the masses and productive forces of our country at an unprecedented rate. In a historically short period of time, the Soviet people, guided by the Communist Party, constructed a socialist society and made enormous advances in development of all branches of the national economy, science and culture.

It is only under Soviet power that conditions were created for radical changes in organizing public health care and medical research, which reflected the constant concern of the Communist Party and government about the health and welfare of the Soviet people. All opportunities were provided for the successful development of a direction that was new in those times, aviation medicine, which emerged as a result of the appearance and continuous refinement of aviation.

Some aspects of theoretical and practical medical support of aviation began to be developed in Russia even before the Great October Revolution; however, there were few such studies and, in some cases, they were quite elementary, which was in essence consistent with the level of aviation at that time. After establishment of Soviet power, the Party and V. I. Lenin personally began to devote much attention to development of aviation and use thereof to protect the world's first nation of workers and peasants. Within literally a few days after the revolution, by order of V. I. Lenin, the first socialistic aviation detachment was formed to defend Petrograd. In January 1918, by order of the republic's Revolutionary Military Council, it was stipulated that all the existing aviation units and schools be completely preserved for the working people. At the same time, medical care was being organized for aviation specialists fighting on the fronts in the civil war and against foreign interventionists. Physician posts were added to the staff of many aviation units and other formations, and later medical subunits [podrazdeleniya] were created in aviation schools and fields. The medical admissions commission, organized in 1920 under the Main Administration of the Red Air Corps, was

of basic importance to screening of flying school cadets and investigation of the effects of flight work conditions on the human body.

In the early 1920's, aviation medicine did not consist of a clearcut system of knowledge, and it dealt with a relatively narrow range of problems that flying practice posed more and more insistently. Even at the early stages of learning to fly on heavier than air craft, it was easy to see that piloting such craft was one of the most complex forms of human activity under unique conditions. Further development of aviation and accumulation of knowhow revealed that, for successful piloting of an aircraft, not only professional skill and ability were required, but specific physical and psychological qualities. Facts indicative of the adverse effect on the human body of a number of flight conditions stimulated work on theoretical and practical problems related to medical implementation of safe and effective flight work.

Organization of the central psychophysiological laboratory in 1924 was an important stage in the inception of Soviet aviation medicine; this laboratory was intended not only for the study of flight work in its psychophysiological aspect, but to work out medical requirements as to the physical condition of flight personnel. S. Ye. Mints and N. M. Dobrotvorskiy made a large contribution to the creation of this laboratory and its subsequent activity. The latter served as scientific administrator of the laboratory for several years, and he was not only an erudite aviation physician, but an experienced clinician.

Such well-known specialists in aviation medicine as P. I. Yegorov, V. G. Mirolyubov, I. K. Sobennikov, V. V. Strel'tsov, N. A. Vishnevskiy, A. V. Lebedinskiy and G. G. Kulikovskiy originated from the central psychophysiological laboratory; they laid the scientific foundation for the main branches of aviation medicine: aviation physiology and hygiene, aviation ophthalmology and otorhinolaryngology, expert medical certification of flight personnel.

Implementation of the grand plan to industrialize the country and the aggressive aspirations of imperialistic forces with regard to the Soviet Union caused rapid development of our aviation in the 1930's. Concurrently, there was deployment of a network of scientific research institutions to deal with problems of aviation medicine. Scientific research laboratories of aviation medicine were organized in the Civil Air Corps, and chairs and sections of aviation medicine were opened in a number of educational and research institutions.

With such a research base, Soviet aviation physicians succeeded in those days in solving a number of important problems set forth by flight practice. In particular, there was development of physiological principles of supplying aircraft crews with oxygen at high altitudes, medical support of extended flights was organized; there was substantiation of a rational schedule for flight work and flight crew nutrition, etc. V. G. Mirolyubov, V. A. Spasskiy, A. P. Popov, A. P. Apollonov, D. Ye. Rozenblyum, N. A. Vishnevskiy and others made a large contribution to the development of aviation medicine in the prewar years.

Along with development of problems of direct medical support of flights, much attention was devoted to creation of a scientifically substantiated system of measures referable to medical supervision of flight personnel and safeguarding their health. Such a system was adopted, and it included dynamic medical supervision of flight personnel, annual certification by medical flight commissions, constant investigation of the effects of flying on the health of each pilot, navigator and other aircraft crew members, as well as implementation of the necessary therapeutic and health-improving measures. Expert medical flight certification was based on the principle of strictly individual evaluation of health status and fitness for flying.

During the Great Patriotic War, Soviet aviation medicine gained much knowhow in medical support of combat missions, organization of care and evacuation of the sick and wounded, safeguarding health and efficiency of aviation specialists under the rigorous conditions of wartime. Aviation physicians were actively involved in determining the permissible combat mission load, searching for flight crew casualties who had made forced landings or had abandoned their aircraft away from their base airport; they implemented administration of the necessary care to such crews and evacuation thereof to medical institutions, which aided in saving and speedy return of valuable flight personnel to the ranks.

In 1944, aviation hospitals were created for treatment and expert medical certification of flight personnel; they played a large role in providing qualified treatment for the wounded and sick referable to the flight and engineering personnel, as well as expert medical certification with due consideration of the specifics of flight work and wartime requirements.

It should be noted that, on the basis of medical analysis of the nature of combat injuries to flight personnel, several refinements were made in aviation technology to alleviate the combat activity of aircraft crews and improve their protection from the enemy's fire.

The rich knowhow gained by aviation physicians with regard to comprehensive medical support of combat operations was used in the postwar years for continued upgrading of organization and work methods of the medical service of our military aviation.

After the Great Patriotic War, the directions and rate of development of aviation medicine were determined by the advances with regard to development of new types of aviation technology and introduction in aviation practice of the achivements of the scientific and technological revolution. The development of high-altitude and jet aircraft equipped with hermetic cabins and ejection devices to save crews in emergency situations made it necessary to provide physiological substantiation of conditions of pressure changes in cabins and parameters of impact G forces during ejection, as well as to develop means of protection against hypoxia in the event of depressurization of cabins at altitudes in excess of 12,000 m.

In-depth investigation of the mechanisms of decompression disorders, development of physiological and hygienic requirements of oxygen and breathing equipment and altitude gear of flight personnel were begun on the basis of the new conditions and distinctions of flight activity; the search was continued for means of increasing resistance of the organism to prolonged accelerations and measures to assure safe ejection over a wide range of altitudes and flying speeds. Specialists in aviation hygiene were concerned with development of systems of air conditioning in aircraft cabins and comfortable flight gear; they solved problems of protection of aviation specialists from the deleterious effects of toxic components of fuel, oil and other technical fluids. Much effort was applied to develop rations and organize inflight nutrition.

As aviation technology continued to become more complicated and with successful solution of problems of life support and protection of crew members from adverse flight factors, there emerged an urgent need to concentrate on the study of psychophysiological distinctions of flight activity to determine the means of increasing the efficiency and reliability of an individual's work when piloting a complex, high-speed and maneuverable aircraft. One of these routes was the involvement of aviation medicine specialists in the designing and development of new aircraft, creation of various aircraft systems and cabin equipment for the purpose of maximum adaptation thereof to the psychophysiological capabilities of man. At present, there is the necessary theoretical and methodological foundation for such work.

Another means of improving the reliability of man in the man--aircraft--environment system was the refinement of medical and psychological screening in aviation. While determination of fitness for flying with respect to physical condition has been practiced for a long time, psychological screening for aviation was adopted on a broad scale considerably later. As a result of numerous experimental investigations and practical verification, informative psychological methods were developed for screening and expert evaluation of flight personnel, and equipment was developed that permits simultaneous screening of a group of individuals. Attention is concentrated mainly on the study of operator qualities of the subjects (distinctions referable to attention, memory, thinking), since flight work began to be characterized primarily by intensive mental activity, which requires the perception and processing of a large amount of information, diverse in form and significance, at a specified [forced] rate.

When at the controls of modern aircraft, pilots have to operate several hundred instruments, levers, buttons and switches within markedly limited time, so that the use of all flying and tactical capabilities of an aircraft became limited, not infrequently, by the psychophysiological capabilities of man. For expressly this reason, it became necessary not only to adapt technology to man, but to develop in the latter maximum capabilities with regard to controlling it, to find the most effective methods of teaching and training pilots, as well as objective evaluation of the level of their professional training. Specialists in aviation medicine are conducting much work in this direction. Physicians participate actively in psychophysiological

training of flight personnel, which includes theoretical and practical studies of the effects of flight factors on the organism, learning how to act in unique situations, special testing and training in pressure chambers, ejection simulators and oxygen conditioning instruments. As a result, flight crews develop physiological and psychological readiness for flights.

Pilot training on complex simulators is of particular importance; they develop not only sensorimotor skills in piloting an aircraft under various conditions, but operational thinking and memory. Aviation physicians have developed methods and criteria for objective evaluation of the dynamics of a pilot's functional state during training on aircraft simulators. In particular, it was established that when learning specific exercises, the quality of pilot performance becomes stabilized earlier than the indices of his physiological functions, which reflect the degree of nervous and mental tension. And it is only stabilization of these functions on a specific individual level that can be indicative of adequate retention of flight skills.

A method of psychophysiological analysis of tracings of control movements of a pilot on a trainer and in actual flight has also been proposed and tested; it permits evaluation of the degree of emotional tension, general condition and readiness for performance of a specific assignment.

Medical determination of flight fitness has also made considerable strides; it is one of the main branches of aviation medicine [or expert medical flight certification]. Scientific substantiation of differentiated requirements as to physical condition of different categories of flight personnel was obtained as a result of special research and analysis of many years of practical experience. The most modern objective methods of psychophysiological and clinical examination began to be used for medical certification of flight personnel. In-depth studies are in progress of the causes of disqualification of flight personnel for health reasons, and measures are being developed to prevent morbidity among flight personnel referable to occupational factors, as well as to prolong the period of flight activity.

At the present time, specialists in aviation medicine are concentrating on refinement and development of new methods of obtaining information about a pilot's condition during a flight, the degree of tension of his physiological functions during performance of various flight missions, the nature of his reactions and actions under unusual flying conditions. They make it possible to determine the psychophysiological content of pilot activity, determine his capabilities and disclose the mechanisms of adaptation of the organism to flight conditions. All this helps obtain data for stricter standard setting with regard to the environment of aircraft cabins, formulate requirements with respect to flight crew screening, including individual psychological screening, rational training, instruction and preventive measures.

It is a known fact that the efficiency of a pilot is not determined solely by his physical condition and functional level of physiological systems, but

also by psychological factors: individual psychological distinctions, conditions of group interaction of a crew, ethical [moral] and psychological training, etc. For this reason, the ways and means of monitoring the condition of a pilot should take into consideration and, as much as possible, assess all aspects of his training for flying. Thus, a complex problem arises, and its solution requires the joint efforts of physicians, psychologists and pedagogues.

The rapid development of rocket technology in the 1950's made it possible to start exploration in space near earth. The question of man's flight into space appeared on the agenda, and this was done, for the first time in the world, in our country. This historic flight, like the subsequent manned flights on spacecraft, made it necessary to resolve new and complex problems related to life support for man, and aviation medicine was found to be closest to them. A new branch of medical science emerged on its basis and began to develop rapidly, we refer to space medicine, which makes use of all the advances in the area of support of manned flights in air.

Spacecraft flights, like flights in aircraft, inevitably involve exposure of the human body to a number of factors due to the dynamics of flight (acceleration, vibration, noise, weightlessness and others), the influence of the environment (highly rarefied atmosphere, radiation, low temperatures, etc.), the fact that crews have to remain in cabins of limited size, which is associated with restricted mobility, respiration in an artificial gas environment, change in circadian rhythms. Cosmonauts, like flight personnel, must undergo comprehensive screening with regard to physical condition and individual psychophysiological traits.

It has become possible to develop, in the near future, so-called aerospace craft for missions in space in the vicinity of earth, which can take off and land like ordinary aircraft. In this respect, it is quite justified to refer to the inception and development of aerospace medicine.

The vast experimental and theoretical material accumulated in the field of aviation medicine, general physiology and hygiene, along with the experience gained in back-up of flights in stratosphere balloons and cruising in submarines served as the basis for subsequent work in the field of developing space medicine. One of the main problems to be solved was investigation of the effects of weightlessness on man's condition and performance. In view of inadequate knowledge of the mechanism and sequelae of weightlessness and cosmic radiation, it was necessary to conduct experiments with animals involving vertical launching of rockets and on artificial satellites of earth.

On the basis of these studies, it was concluded that the set of factors involved in a brief space flight does not present an immediate threat to human life or health. Animal experiments made it possible to bypass the stage of experimental suborbital manned flights and to begin implementation of the program of manned space flights with the single orbit flight of Yu. A. Gagarin on 12 April 1961.

The main objective of short-term (several days) flights in space was to continue investigation of the mechanisms of effects of weightlessness and other factors on the human body and to forecast the possibility of longer flights. For this purpose, the indices of the main physiological functions in flight, physical and mental fitness were recorded, and the cosmonauts were submitted to a comprehensive postflight clinical and physiological examination.

Investigation of human fitness [or efficiency] as an element in the control of a spacecraft and its systems is a relatively new direction in space medicine. These studies, which were conducted in the course of actual flights and in experimental simulation, not only demonstrated man's great capabilities, with regard to performance of the most diverse tasks, but yielded recommendations on optimization of the control system and further refinement of spacecraft construction.

Most of the paramount problems of aerospace medicine have been solved; however, in spite of the advances made, some problems still require more work. These problems are related primarily to the tendency toward increased inconsistency between the capabilities of aerospace technology and psychophysiological capabilities of man. The speed and dynamic nature of situations in a normal flight are at the limit or even exceed the rate of neuropsychic processes involved in analyzing a situation, choosing the optimum decision and actions by the pilot or cosmonaut.

It must be mentioned that many of the results of physiological, psychophysiological, hygienic and other research in aerospace medicine not only furnish concrete answers to questions related to flights on different types of flying machines, but have a direct bearing on implementation of a number of other forms of human endeavor and public health care as a whole. We refer, for example, to the possibility of using the equipment and methods developed in aerospace medicine for testing the functional systems of the organism during performance of various forms of activity, use of data on man's adaptation and readaptation to new living conditions, man's exposure to low barometric pressure and the effect on him of pressure changes, methods of psychophysiological screening and evaluation of psychological compatibility of groups, etc.

Thus, not only does aerospace medicine enrich our knowledge in a specific area of human endeavor, flying in aircraft serving various purposes, it also aids in development of other branches of medical science.

The Central Committee of the CPSU and Soviet government are devoting constant attention to the development of aviation. Soviet aviation medicine is offering major advances in the field of theoretical research and practical use of the results thereof on the 60th anniversary of the Great October Socialist Revolution. Joint ["complex"] research is being practiced more and more in the field of aviation medicine with allied scientific directions. There is intensification of ties, scientific collaboration and coordination of work among socialist countries.

It is the duty of specialists in aviation medicine and all aviation physicians to solve the problems facing them and to keep in step with the development of technology, implementing advance development of pressing scientific problems.

SURVEYS

UDC: 612.014.477:612.76

BIOMECHANICAL CRITERIA OF ARTIFICIAL GRAVITY

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian No 5, 1977 pp 18-25

[Article by I. Yu. Sarkisov and A. A. Shipov, submitted 24 Mar 77]

[Text] There are at least three closely interrelated aspects to the question of artificial gravity (AG): engineering-technical, engineering-housekeeping and biomedical [1]. The engineering and technical aspect is determined by the technical readiness of society to tangible implemention of the idea of creating gravity by means of rotation. The engineering-houskeeping aspect is related to the need to provide the usual living conditions for man in a revolving system. Finally, the biomedical aspect is determined by the physical and physiological effects arising when man is exposed to rotation.

In this work, we shall discuss the biomechanical effects and the physiological sequelae they induce, as observed in rotating systems with AG that are usually not manifested under the usual living conditions. The existence of limitations to permissible variations of physiological functions leads to the appearance of biomechanical criteria of artificial gravity ["weight"], which impose certain restrictions on the dimensions and angular rotational rate of a system with AG [1-9].

In order to obtain the biomechanical criteria of AG, let us compare the forces acting on a tangible point of mass *m* moving along earth's surface to the forces acting on the same point in a rotating orbital system.

The sum of all forces acting on a mass point determines the force of gravity, or weight, which can be described by the following equation, when on earth:

$$\vec{F} = m\left[(R/r_0)^2\vec{g}_0 + \vec{\Omega}_0\times(\vec{\Omega}_0\times\vec{r}_0) + 2\vec{\Omega}_0\times\vec{V}\right], \quad (1)$$

where g_0 is free-fall acceleration in the vicinity of earth's surface; $\vec{\Omega}_0$ and R are angular rate and radius of earth; $\vec{V}$ and $\vec{r}_0$ are the rate of movement of the mass point in relation to the earth's surface and its distance from the center of the earth.

The first two addends [1] describe the static component of weight and the third, the dynamic component that arises only when the point moves. The static component is due to the existence of gravitation and it arises as a result of earth's rotation by a centrifugal force. The dynamic component is determine by Coriolis force, which appears when the point moves in relation to earth. At the usual rate of man's movement on the earth's surface, the second and third addends are $3 \cdot 10^4$ times smaller than the first [8]; for this reason, they can be disregarded in discussing the biomechanical effects of movement, and earth can be considered an inertial reading [reference] system. In this case, the weight of the mass point is determined virtually solely by gravitational attraction, and it is unrelated to movement of the point:

$$\vec{F} = m\,(R/r_0)^2 \vec{g}_0. \tag{2}$$

The weight of the mass point in a rotating orbital system is determined from the equation:

$$\vec{F}' = m\left[\vec{\Omega}\times\left(\vec{\Omega}\times\vec{r}\right) + 2\vec{\Omega}\times\vec{V}\right], \tag{3}$$

where $\vec{\Omega}$ and $\vec{r}$ are angular rate of uniform rotation and radius of the system; $\vec{V}$ is the rate of relative movement of the point.

In equation (3), the first addend is the static component of AG or centrifugal force induced by rotation of the system. The static component of AG is a "useful" force, which should replace earth's gravity (2). The dynamic component of AG is described by the second addend and it is the Coriolis force arising only when the point moves in relation to the rotating system.

If we compare the weight of the mass point on earth (2) to the static component of AG (3), we can readily detect that they are different. Indeed, the gravitation field of earth is a central one, i.e., all forces of interaction are directed toward the center, while the AG field is axial. The gravitation forces decrease as the distance from the center of earth increases at a rate that is inversely proportional to the square of the distance, while the magnitude of centrifugal forces increases linearly with increase in rotational radius of the system.

According to equation (3), the weight of the mass point in a system with AG is determined only by inertial forces. It should be noted that, at the usual rate of man's movement and high angular rate of the system, the static and dynamic components of AG are of the same order, unlike conditions on earth. In this case, the effects of rotation may become significant to a number of physiological functions.

Of course, one can obtain local equivalence of the field of centrifugal forces and earth's gravitation field by appropriate selection of rotation

parameters. However, perhaps local equivalence is not enough to preserve identical function of physiological systems. The latter is related to the fact that, on the one hand, the human body cannot be equated with a point when dealing with various physiological effects of AG; on the other hand, as we have already mentioned, the field of inertial forces generated by rotation differs from earth's gravity field.

Let us discuss in greater detail the consequences of differences between earth's gravity fields and AG that have a direct or indirect effect on fitness and comfort of man in a rotating system. For this purpose, using equations (2) and (3), let us determine some physiologically significant physical parameters for conditions on earth and the system with AG and let us compare them. The compared physical parameters are summarized in the Table. The Table also lists the restrictions with regard to permissible relative changes in such physical correlations as $\Omega^2 r$, r, Ωr and Ω, which are biomechanical criteria of AG. All of the formulas listed in the Table were obtained on the basis of laws of mechanics written down in an inertial (earth) and noninertial (rotating) systems. The laws of mechanics were applied in the description of elementary physical models, which permit, for example, determination of the center of gravity of the human body and distribution of hydrostatic pressure in blood vessels of the extremities, as well as description of function of the vestibular apparatus in a moving system, etc.

The force field of a system with AG is perceived differently by man, depending on whether he is moving or not; for this reason, it would be rational to divide the biomechanical criteria of AG into static and dynamic ones.

One of the important static characteristics of the AG force field is the magnitude of AG at "floor" level of the rotating orbital system (see Table). The magnitude of AG has a direct effect on man's ability to move and perform various work operations [4-9]. It is assumed that it can be lower than on earth, and that the conditions of man's vital functions do not change appreciably [6-9]. The lower range of AG according to biomechanical indices is determined by the force of friction between the soles of the feet and the floor, which is required for movement. Indeed, with decrease in AG there is also a decrease in frictional force and, starting at a certain limit, it could be inadequate for normal locomotion. The upper limit of AG is, of course, determined by a magnitude that equals earth's gravity.

Thus, AG of $\Omega^2 r$, which is the first biomechanical criterion of AG, should change in the following range:

$$\underline{C}\leqslant\Omega^2_r\leqslant\overline{C}, \tag{4}$$

where $\underline{C}\approx 0{,}3$ g [4—9], $\overline{C}\approx$ g.

A different law of change in AG, as compared to the terrestrial law, depending on the distance to the axis of rotation results in the fact that the mass point has an inconstant weight in the system with AG (see Table).

Physical effects and biomechanical criteria of AG

Physical effect of force field significant to man	Earth	System with AG	Biomechanical criterion of AG
Gravity at "floor" level	$F=m(R/R+h)^2 g_0 \approx mg_0$	$F'=m\Omega^2 r$	$\underline{C} \leqslant \Omega^2 r \leqslant \overline{C}$
Mass point weight at height h	$F_h = m(1-2h/R)g_0 \approx mg_0$	$F'_h = m\Omega^2(r-h)$	$\Delta F'_h / F'_{h=0} = h/r \leqslant C_r^1$
Weight of body with length h	$Q=(1-h/R)\,Q_0 \approx Mg_0$	$Q'=(1-h/2r)\,Q'_0 \approx M\Omega^2 r$	$\Delta Q'/Q'_0 = h\,2r \leqslant C_r^2$
Position of center of gravity	$X=\frac{1-4h/3R}{1-h/R}\cdot\frac{h}{2}\approx h/2$	$X'=\frac{1-2h/3r}{1-h/2r}\cdot\frac{h}{2}$	$\Delta X'/X' = h/6r \leqslant C_r^3$ $r \to \infty$
Hydrostatic pressure in blood vessels of limbs	$P=(1-h/R)P_0 \approx \rho g_0 h$	$P'=(1-h/2r)P'_0 \approx \rho\Omega^2 rh$	$\Delta P'/P'_0 = h/2r \leqslant C_r^4$
Shift from expected body fall point	$d=\frac{2}{3}\,h\Omega_0(h/g_0)^{1/2}\approx 0$	$d'=[(a^2-1)^{1/2}-\mathrm{tg}^{-1}(a^2-1)^{1/2}]r$, $a^{-1}=1-h/r$	$\Delta d = d' \leqslant C_r^5$
Moment of Coriolis force with radial movement	$\widetilde{M}_r \approx Mh\Omega_0 v$, $\widetilde{M}_Q \approx hQ_0$	$\widetilde{M}'_r \approx Mh\Omega v$, $\widetilde{M}'_{Q'} \approx hQ'$	$\Delta\widetilde{M}'_r/\widetilde{M}'_{Q'} \approx v/\Omega r \leqslant C^1_{\Omega r}$
"Dynamic" weight with tangential movement	$Q_\tau \approx Q_0 + M(\Omega_0 + v/R)^2 R \approx Mg_0$	$Q'_\tau \approx (1+v/\Omega r)^2 Q'$	$\Delta Q'_\tau/Q' = (1+v/\Omega r)^2 - 1 \leqslant C^2_{\Omega r}$
Additional moment	$\widetilde{M}g \approx J\omega\Omega_0 \approx 0$	$M'g \approx J\omega\Omega$	$\Delta\widetilde{M}' = \widetilde{M}' \leqslant C^1_\Omega$
Angular deviation of cupulae of semi-circular canals	$\theta_i \approx \tau_i\Omega_0 \leqslant \theta_i^*$	$\theta'_i \approx \tau_i\Omega$	$\Delta\theta'_i = \theta'_i \leqslant C^2_\Omega$

Note: If A is a certain physical dimension on earth, then A' is the designation of the same dimension in the system with AG and $\Delta A/A$ is its relative change. $\underline{C}$, $\overline{C}$, C_r^i, C_Ω^j and C_Ω^K ($i = 1, \ldots 5$, j, $k = 1, 2$) are the permissible limits of relative change in physical dimensions. F is gravity; m is point mass; R and Ω_0 are the radius and angular velocity of earth; g_0 is free-fall acceleration near earth's surface; h is the height of the point or of man; F_h is the weight of point mass at height h from the arbitrary zero level (level with $h = 0$); r and Ω are the radius and angular rate of the system with AG; X is the coordinate of man's center of gravity estimated from the arbitrary zero level; P is hydrostatic pressure in blood vessels of the limbs; P_0 is the same at arbitrary zero level; ρ is mean density of blood; d is the shift of object falling point from expected point; M is human body mass; $\widetilde{M}_r$ is the tilting moment of Coriolis force with radial movement of man at the rate of v; $\widetilde{M}_Q$ is the moment of gravity forces; $\widetilde{M}_g$ is the additional moment required for the body to turn at angular rate ω in the rotating system; J is the moment of body inertia; Θ_i is angular deviation of the cupula of the ith semi-circular canal; τ_i is time constant of the ith cupuloendolymphatic system; Θ_i^* is threshold deviation of cupulae.

For the same reason, the way man perceives his own weight depends appreciably on the magnitude of the ratio of his height to radius of rotation h/r (see Table). Because of the existence of this correlation, when a man is seated he will feel he weighs more than when he is standing [6-9]. It must be borne in mind that on earth there is also a decrease in perceived weight, but it constitutes an infinitesimal value, $3 \cdot 10^{-7}$. In a system with AG, with a radius of rotation equaling man's height, this ratio is 2. In addition to the above effects, a stationary man also observes a unique phenomenon [5-9], such as shifting of the point of fall of an object from the expected point (see Table).

For systems with short radii, the above physical dimensions differ appreciably from terrestrial ones (see Table), and the differences are at a maximum with $r = h$. Consequently, each of the above physiological sequelae imposes certain restrictions on the minimum radius of rotation of the system, and this is the second biomechanical criterion of AG. Of all the restrictions, the decisive one is that which limits the radius to a maximum degree.

Thus,

$$\underline{C}_r \leqslant r, \quad \underline{C}_r = \max \left[C_r^i\right], \; i = 1 \ldots 5. \tag{5}$$

The AG gradient is often described [8] by the h/r ratio, and it is assumed that with $h/r \leqslant 0.15$ man would not perceive an AG gradient or, at any rate, would not experience discomfort [6, 8, 9]. This ratio makes it possible to approximately determine the value of C_r.

Let us now turn to the discussion of dynamic criteria of AG. Various movements of a man during a space flight with artificial gravity involve his exposure to concomitant dynamic factors. Indeed, when man moves in any rotating system, Coriolis forces appear and they make it difficult to perform coordinated movements of the arms and legs, radial and tangential movements, as well as manipulations such as carrying weights, jumping, decanting liquids, etc. [2-10]. Coriolis accelerations may be the cause of some optical illusions and, in the case of repeated exposure to them, they could cause development of motion sickness [6]. Coriolis accelerations are perceived by the proprioceptors of the human body and otolith receptors of the vestibular system. The greater the Coriolis forces, the more significant these effects are. The tilting moment of Coriolis forces when man performs radial movements and the change in static weight of a man during tangential movement in the same or opposite direction to rotation merit special attention (see Table). The relative changes in the dimensions considered should be confined to specific ranges. The maximum restrictions are imposed on the magnitude of relative change in the weight of the human body, which should not exceed 20% [9]. Thus,

(6)

Restrictions referable to linear rate Ωr of the rotating system were obtained from the restrictions imposed by Coriolis forces, and this is the third biomechanical criterion of AG.

The accelerations that arise with angular movements in a rotating system are called precessional and they are angular accelerations [11, 12]. And additional moments of forces (see Table) must be applied [9] for rotation of objects about axes that do not coincide with the axis of rotation of the system. In this case, the effects of precession accelerations are perceived by the body's proprioreceptors.

With rotation of the head about axes that are not parallel to the axis of rotation of the system, a different pattern of stimulation of receptors of the vestibular semicircular canals, as compared to the usual conditions, is created because of appearance of precession accelerations. Information is delivered to the central nervous system about a head movement that does not correspond to the actual turn, in contradiction to the visual and proprioceptive information about the performed movement [13]. As a result, spatial disorientation, undesirable compensatory movements of the body and general malaise may appear [6, 14-16]. With increase in magnitude of precession accelerations, the above disturbances develop more rapidly and motion sickness may appear. Let us mention that man is also exposed to precession accelerations in earth. They are much smaller than the accelerations that occur in a rotating system with AG. The order of magnitude of accelerations is determined by the ratio of angular rate of earth to angular rate of the system. For example, in a system rotating at an angular rate of 10 r/min, precession accelerations and additional moments of forces are $1.5 \cdot 10^3$ times greater than for the same movements on earth.

Apparently, to preserve man's normal efficiency [fitness], there must be limitations to the additional moments of forces that must be applied for objects to turn in a system with AG, as well as to deviations of cupulae of semicircular canals (see Table):

$$C_{\Omega r} \leqslant \Omega r, \; C_{\Omega r} = \max \left[C^1_{\Omega r} \; C^2_{\Omega r}\right]. \tag{7}$$

The top limit for the angular rate is determined by the functional distinctions of the semicircular canals in the system with AG. According to experiments conducted under terrestrial conditions, the angular rate should not exceed 6 r/min [9, 12].

Thus, inequality (7), which imposes a restriction on angular rate of rotation Ω of the system, introduces the fourth biomechanical criterion of AG.

The above comparative analysis of the fields of the earth's and artificial gravity demonstrated a substantial difference between them. For this reason, when developing systems with AG, we can refer only to arbitrary equivalence of the artificial force field and that of earth, which is characterized by insignificance of physiological effects of rotation. And this principle was

used as the basis for derivation of biomechanical criteria of AG. By altering the radius and angular rate of the system, and thereby changing the field of inertial forces, it can be made as close as one wishes to the physiological gravitation field of earth. Ultimately, the problem amounts to determination and substantiation of the optimum combination of radius and angular rate of the system with AG, with which man could exist in it with adequate comfort and safety to health.

If we sum up this discussion of biomechanical criteria that can be used to choose the optimum ratio of radius and angular rate of rotation of a system with AG, we can readily see that they are all physically determined by the difference between the force field of the system with AG and the force field of earth. Thus, appearance of the first criterion $\Omega^2 r$ (4) is due to the magnitude of AG. The second criterion r (5) limits the possible dimensions (radius of rotation) of the system. It is determined by both the spatial heterogeneity of the force field of the rotating system and the law of change in forces as the distance from the rotation axis increases, which is different from the law that prevails on earth. The third and fourth criteria, which restrict the linear Ωr (6) and angular Ω (7) rates of rotation of the system, respectively, are determined by the substantial lack of inertia in the AG field.

We should discuss one more restriction, unrelated to the preceding ones, that must be taken into consideration in designing systems with AG. This restriction is imposed by the technological and economic potential of society, which determines the maximum and designwise acceptable dimensions of systems with AG: $r \leqslant \overline{C}_r$.

Thus, the points in the plane with coordinate axes Ω and r (see Figure), that satisfy the following inequalities

$$\begin{aligned} &\underline{C} \leqslant \Omega_r^2 \leqslant \overline{C}; \\ &\underline{C}_r \leqslant r \leqslant \overline{C}_r; \\ &C_{\Omega r} \leqslant \Omega r; \\ &0 < \Omega \leqslant C_\Omega, \end{aligned} \tag{8}$$

are permissible from the standpoint of assuring normal vital functions of man in a space system with AG.

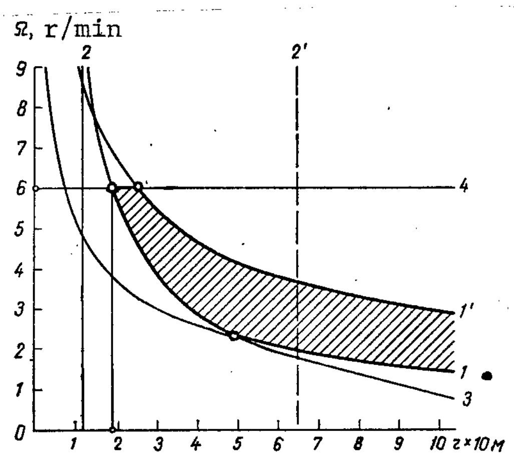
Let us consider the system of inequalities (8). Simple calculations, which are based on the results of ground experiments with rotating systems, enable us to approximately determine the numerical values of the following coefficients: $\underline{C} \approx 0.3\ g$, $\overline{C} = g$, $\underline{C}_r \approx 12$ m (with man's height of 180 cm), $C_{\Omega r} \approx 12$ m/s) and $C_\Omega = 6$ r/min.

Let us drop the right part of the second inequality in (8), which takes into consideration the nonbiological criterion of AG ($r \leqslant \overline{C}_r$). Then the graphic solution to the system of inequalities (8) demonstrates the area of permissible radii and angular rates of the system, which is shaded in the Figure.

This area is formed by the intersection of two curves of the hyperbolic type, 1 and 1', hyperbole 3 and lines 4 and 2 (see Figure). Each curve is directly related to a specific biomechanical criterion of AG. From the reciprocal location of the curves, we see that line 2 does not intersect the shaded area (see Figure), for which reason we can disregard the dimensional restriction $\underline{C}_r \leqslant r$, which is determined by the AG gradient. Determination of the numerical values of the above coefficients could result in deformation of this area, but, according to our estimates, there will be no appreciable change in reciprocal position of the curves. Consequently, the shaded area in the Figure is described by fewer inequalities:

$$\begin{gathered}\underline{C} \leqslant \Omega^2 r \leqslant \overline{C};\\ C_{\Omega r} \leqslant \Omega r;\\ C_{\Omega} \geqslant \Omega.\end{gathered} \tag{9}$$

Each point in this area satisfies the system of inequalities (9) and determines the permissible values of the radius and angular rate of the system with AG. For economic reasons, one should select the point corresponding to the smallest radius, which equals approximately 20 m (Ω = 6 r/min). The point is found at the intersection of curves 3 and 4, that are related to the third and fourth biomechanical criteria of AG, respectively.



Graphic illustration of system of of inequalities (8)

Shaded area, set of "physiologically" permissible values of radius and angular rate of system with AG.
1 and 1', hyperbolic types of curves with:
$r = \underline{C}/\Omega^2$; $r = \overline{C}/\Omega^2$;
2) straight line $r = \underline{C_r}$
2') straight line $\underline{r} = \overline{C}_r$
3) hyperbole $r = \overline{C}_{\Omega r}/\Omega$
4) straight line $\Omega = C_\Omega$

Units of measurement of axes of Ω and r are 1 r/min and 10 m, respectively

The physical and physiological effects we have discussed are overtly manifested only in the case of small dimensions and high angular rate of the system (see Figure). Conversely, with a large enough radius and low enough angular rate, these effects become infinitesimal and they can be disregarded. The physical interpretation of this phenomenon is that with the appropriate choice of parameters of rotation, the AG field becomes similar to the gravitation field with regard to its effect on the human body.

Let us mention that the range of permissible radii and angular rates (see Figure) could serve as a theoretical guideline for future design engineering of systems with AG, as well as for planning ground-based and space experiments dealing with adjustment [correction] of values of coefficients $\underline{C}$, $\overline{C}$, $\underline{C}_r$, $\overline{C}_r$, $C_{\Omega r}$ and C_Ω. It should be stressed that, at the present time, it appears feasible to develop systems with radius of rotation not exceeding 25 m and level of artificial gravity equaling that of earth. Since a lower AG level is permissible from the biomedical point of view [4-9], the radius of the system could also be smaller.

BIBLIOGRAPHY

1. Kotovskaya, A. R.; Galle, R. R.; and Shipov, A. A. KOSMICHESKAYA BIOL. [Space Biology], No 2, 1977, pp 12-19.

2. Loret, B. J. AEROSPACE MED., Vol 34, 1963, pp 430-441.

3. Thompson, A. B. in "Symposium on the Role of the Vestibular Organs in Space Exploration," Washington, 1965, pp 233-239.

4. Faget, M. A., and Olling, E. H. in "Third Symposium on the Role of the Vestibular Organs in Space Exploration," Washington, 1968, pp 7-16.

5. Stone, R. W.; Piland, W. M.; and Letko, W. in "Fourth Symposium on the Role of the Vestibular Organs in Space Exploration," Washington, 1970, pp 331-343.

6. Ramsey, H. R. HUMAN FACTORS, Vol 13, 1971, pp 533-542.

7. Newson, B. D. SPACE LIFE SCI., Vol 3, 1972, pp 192-197.

8. McGaughy, R. E., and Hoffman, D. B. J. ASTRONAUT. SCI., Vol 18, 1971, pp 323-354.

9. Stone, R. W. in "Fifth Symposium on the Role of the Vestibular Organs in Space Exploration," Washington, 1973, pp 23-34.

10. Letko, W. Ibid, pp 67-72.

11. Sarkisov, I. Yu., and Shipov, A. A. IZV. AN SSSR. SERIYA BIOL. [News of the USSR Academy of Sciences, Biology Series], No 3, 1974, pp 425-428.

12. Graybiel, A. in "Fundamentals of Space Biology and Medicine," Moscow, Vol 2, Book 1, 1975, pp 265-323.

13. Sarkisov, I. Yu., and Shipov, A. A. IZV. AN SSSR, SERIYA BIOL., No 6, 1974, pp 908-913.

14. Graybiel, A. ENVIRONM. BIOL. MED., Vol 2, No 2, 1973, pp 91-138.

15. Idem, in "Fifth Symposium on the Role of the Vestibular Organs in Space Exploration," Washington, 1973, pp 35-39.

16. Guedry, F. E. in "Fourth Symposium on the Role of the Vestibular Organs in Space Exploration," Washington, 1970, pp 45-51.

UDC: 616.45-001.1/.3-02:612.014.477

CHANGE IN GRAVITATION LEVEL AS A STRESS FACTOR

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian No 5, 1977 pp 25-32

[Article by L. V. Serova, submitted 24 Nov 75]

[Text] Gravity is a constant for the inhabitants of earth and, perhaps, it is expressly for this reason that experimental investigation of its effects and mechanism of action began very recently. We can concur with A. Smith, who writes: "If gravitation were as variable as many other environmental factors, it would be easier to understand its effects" [1].

Hypotheses were repeatedly expounded that gravitation determines the shape and size of animal organs, and that a change in gravity, both in the direction of increase and weightlessness, is not indifferent to the organism [2-11]. However, experimental research on the effects of altered gravitation has only been pursued for the last two decades. Originally, it was assumed that, since the inhabitants of earth are adapted through evolution to 1 G conditions, a change in gravity, both in the direction of hypergravitation and weightlessness, could lead to serious functional and structural changes beyond the physiological range and, perhaps, in the case of prolonged exposure, it could be incompatible with life.

Theoretically, we can assume that there are two ways in which altered gravitation affects the organism: 1) specific (mechanical), which is related to a change in reciprocal position of organs and tissues, as well as different components of cells and tissues, and to a change in energy expended to overcome gravity; 2) nonspecific, on the order of a stress reaction.

Evidently, the extent of manifestation of the specific effect of altered gravitation will depend on the size of the organism, and the larger the animal, the greater the effect; the nonspecific effect will be determined by the level of organization of the animal's nervous and endocrine systems, just like resistance of the organism to G forces, hypoxia and other extreme factors is determined by its reactivity [12-14].

There have been published surveys [1, 15] summing up the experimental data accumulated to date on the effects of altered gravitation on structural and functional characteristics of mammals and man.

Many data were obtained with regard to prolonged exposure of animals to hypergravitation created by rotation on a centrifuge [16-29]. In most cases, centrifuging led to retarded animal growth. There was a particularly marked retardation of weight gain at the early stages of hypergravitation; then, with low accelerations (2-4 G) normalization occurred and with high ones, emaciation.

Interestingly enough, while mammals (rats, mice, hamsters) lost considerable weight at 4 G, turtles (red-eared) grew twice as fast under such conditions than in the control [28], and this can apparently be attributed to the distinctions of neuroendocrine regulation and metabolism in animals of different classes [14].

Interest in questions of viability and basic possibility of a normal life expectancy in the presence of altered gravitation was apparently the factor that prompted enthusiasm for long-term experiments, in which the animals were rotated in centrifuges for many months and even years, the main studies being pursued at the late stages of exposure to hypergravitation during the period of possible normalization of initial changes.

Evidently, the disappearance of initial changes and adaptation to hypergravitation explain the absence of signs of stress reactions, as well as changes in weight and structure of internal organs in the case of long-term (up to 1 year) exposure to hypergravitation of 3 and even 4 G [22]. But the acute period, which could be called the period of hypergravitation stress, judging by the severe retardation of growth, has been little studied.

Yet experience in research on adaptation of the organism to environmental factors (such as change in gas composition, temperature, etc.) shows that expressly analysis of the early stages of exposure, i.e., the period of development of adaptation, rather than the period of its subsequent stabilization, is the most fruitful. At expressly this time, one can detect the mechanisms with which the organism maintains homeostasis under altered conditions, the "visible stability" that we observe in adapted animals.

In the last few years, a conception is being formed that mammals can endure virtually unlimited exposure to hypergravitation of 2-4 G without serious changes in viability. At the same time, it should be noted that even at 2-3 G, in spite of usual preservation of normal life expectancy, the animals present many signs typical of the stage of depletion of the stress reaction: death of part of the animals, retarded growth, lymphopenia [20-23]. Changes in the adrenals are observed in animals exposed to accelerations of 4 G for 24 h: lowered levels of lipids and ascorbic acid, increased activity of acid phosphatase [30]. There was an increase in concentration of corticosterone in blood plasma of rats exposed to 4.5 G for 1-24 h [23]. The question arises as to whether there is indeed total normalization of the organism in the case of prolonged hypergravitation or is there a new level of reaction, which appears more plausible. Then, in the presence of stability of the main physiological constants, there is a change in reactivity and resistance of the organism, similarly to what we see in adaptation to hypoxia, aging and a number of other situations.

We began our investigations with a series of experiments dealing with the effect of gravitation 100% greater than that of earth (2 G or +1 G to earth's gravity) on growth and development of mammals.

Hypergravitation was created by rotating the animals on a centrifuge-stand, with a 48 cm radius. The animals were rotated around the clock, with daily stops to clean the cages. We used adult mice (males and females), mongrels and CBS (over 500), in the experiments. The animals were put in cages that were compartments on the stand for artificial gravitation; they were 8×8×28 cm in size and we put 5 mice in each. The animals were on a mixed diet, and they were fed both during rotation and when the centrifuge was stopped.

The first experiments were conducted on female mice that were not adapted to hypergravitation; they were put on the centrifuge 11-13 h after mating, and they were examined on the 1st, 2d, 3d, 4th, 5th and 10th days of rotation. It was established that pregnancy is interrupted under such conditions.

Analysis of this phenomenon, which was made by O. V. Volkova et al. [31] for the experimental data we obtained, revealed that the main disturbances begin to appear at the stage of 8 blastomeres as the embryos pass from the oviducts into the uterus. There is also retarded development: on the 6th postfertilization day the flushed blastocytes correspond to the 4th day of normal development. In addition to retarded development, there was irregular cleavage, starting on the 2d-5th day after fertilization; death of embryos and lysis of blastomeres were observed.

Previously, studies were pursued of embryonic development in experiments on mammals, which had been exposed to long-term hypergravitation prior to fertilization, i.e., they were adapted to these conditions. In this case there were virtually no developmental anomalies (in the case of intermittent rotation [16], or else they were considerably less marked than in the above-described experiments [24]. Apparently, the difference in the results is attributable to the fact that we used animals that were not adapted to hypergravitation, and they were put on the centrifuge soon after fertilization.

The fact that anomalous embryonic development under hypergravitation conditions is observed only in nonadapted animals suggests that it occurs as a result of disturbances in regulatory systems of the organism (apparently as a result of a stress reaction by the organism), elimination of which by means of conditioning should also avert anomalous embryonic development, rather than as the result of the direct mechanical effect of a 100% greater gravity on the embryo.

In continuation of our studies, we conducted a series of experiments on mice (male and female) in order to determine the extent of stress changes arising in the organism with prolonged and continuous rotation on the centrifuge. The animals were examined after 7-day exposure to 2 G under the conditions described*

*We chose the exposure time with which a maximum deleterious effect was observed in the preceding experiments.

above. We assessed the severity of stressor changes according to weight of the body and organs, as well as characteristics of the blood system and lymphoid organs, using a quantitative assay of cells in bone marrow, thymus and spleen following the system proposed by P. D. Gorizontov et al. [32-34].

It was established that 7-day exposure to 2 G hypergravitation is associated with 10-25% retardation of growth of mice (male and female), as compared to the control, which generally coincides with the results described in the literature [19, 21, 22, 24, 27]. There is also a decrease in weight of organs--liver, kidneys and myocardium; however, there is no change in weight coefficient of the liver and kidneys, while that of the myocardium even increases, as compared to the control.

Since there is negligible loss of fluid by internal organ tissues under these conditions, it may be considered that the decrease in organ weight is not due to dehydration, but to changes in metabolic processes related to temporary prevalence of breakdown over synthesis, which leads to organ hypotrophy. An increase in expenditure of energy in the presence of hypergravitation, due to the need to counteract the doubled body weight, may be the cause of these changes. The possibility of such reactions is indicated, for example, by the data of Oyama et al. [22, 24], who demonstrated significant activation of lipid metabolism of animals in the presence of hypergravitation, and the data of A. A. Gyurdzhian et al. [17], who described intensified mobilization of nonesterified fatty acids from the lipid reservoirs into blood with single exposure of animals on a centrifuge.

Table 1 lists the characteristics of blood, bone marrow and lymphoid organs of animals examined after 7-day exposure to 2 G. As can be seen in this table, involution of lymphoid organs is observed under these conditions: decreased weight of the thymus and spleen, decrease in absolute quantity of thymocytes and splenocytes. Lymphopenia was demonstrated in blood. There was no change in absolute quantity of karyocytes in bone marrow of experimental animals, as compared to the control. Analysis of weight characteristics, as well as blood, bone marrow and lymphoid organs of animals exposed to hypergravitation for 7 days warrants the belief that, under these conditions, there is a stress reaction by the organism and it is apparently not the direct mechanical effect of hypergravitation, but expressly the stressor effect and changes in neuroendocrine regulation related to the latter that lead to the above-described anomalies of embryonic development of mammals at 2 G.

Since no anomalies of pregnancy are observed in animals adapted to hypergravitation [16, 24], it is logical to assume that they also present no signs of chronic stress or the neuroendocrine changes that determined the disturbances of embryonic development with hypergravitation, i.e., if intermittent rotation, i.e., conditioning, is used prior to continuous exposure on the centrifuge, the above-described signs of stress reactions should not develop.

Table 1. Characteristics of blood, bone marrow and lymphoid organs of mice with hypergravitation (2 G, 7 days)

Experimental conditions	Thymus wt., mg	Thymocytes, millions	Spleen wt., mg	Splenocytes, millions	Bone marrow cells, millions	Blood leukocytes, thou/mm^3	Blood lymphocytes, %
Control	$39,4 \pm 3,7$	$125,8 \pm 19,5$	161 ± 23	$427,0 \pm 46,9$	$22,44 \pm 2,62$	$10,55 \pm 1,16$	$51,2 \pm 3,0$
Hypergravitation (2 G, 7 days)	$15,3 \pm 2,0$ $P < 0,001$	$29,4 \pm 5,9$ $P < 0,001$	101 ± 13 $0,05 > P > 0,02$	$196,9 \pm 11,8$ $P < 0,001$	$21,09 \pm 1,3$ $P > 0,1$	$9,64 \pm 1,02$ $P > 0,1$	$31,1 \pm 1,6$ $P < 0,001$

Table 2. Characteristics of blood, bone marrow and lymphoid organs under the influence of hypergravitation (2 G, 7 days) after preliminary 20-day conditioning on centrifuge (6 h daily)

Experimental conditions	Thymus wt., gm	Thymocytes, millions	Spleen wt. gm	Splenocytes millions	Bone marrow cells, millions	Blood leukocytes, thou/mm^3	Blood lymphocytes, %
Control	$44 \pm 2,2$	$146,2 \pm 18,5$	164 ± 37	$344 \pm 48,9$	$15,78 \pm 2,1$	$15,3 \pm 0,1$	$53 \pm 2,5$
Hypergravitation (2 G, 7 days, after 20-day conditioning on centrifuge	$36,5 \pm 3,7$ $P = 0,1$	$104,7 \pm 18,9$ $P > 0,1$	121 ± 20 $P > 0,1$	$291,3 \pm 91$ $P > 0,1$	$19,6 \pm 1,5$ $P > 0,1$	$15,6 \pm 0,14$ $P > 0,1$	$52,5 \pm 3,5$ $P > 0,1$

Table 3. Characteristics of blood, bone marrow and lymphoid organs of rats after prolonged weightlessness

Experimental conditions	Thymus wt., gm	Thymocytes, millions	Spleen wt., gm	Splenocytes, millions	Bone marrow cells, millions	Blood leukocytes, thou/mm^3	Blood lymphocytes, %
Control	260 ± 36	883 ± 159	611 ± 51	1136 ± 70	$222,4 \pm 14,8$	$11,6 \pm 3,4$	$70,3 \pm 1,5$
Weightlessness 22 days	119 ± 12 $0,01 > P > 0,001$	416 ± 66 $0,02 > P > 0,01$	416 ± 33 $0,01 > P > 0,001$	702 ± 90 $0,01 > P > 0,001$	$177,4 \pm 8,4$ $P = 0,02$	$14,83 \pm 1,3$ $P > 0,1$	$45,4 \pm 2,7$ $P < 0,001$

The basic possibility of adaptation of the organism to hypergravitation, similarly to, for example, adaptation to hypoxia, hyperthermia and other factors, was previously demonstrated in the experiments of A. A. Gyurdzhian et al. [16]: prolonged exposure of animals to accelerations of 1.5-3.0 G "attenuated" the reaction of the organism to subsequent accelerations of 5, 10 and 20 G. Normalization of the organism after many months of rotation of the animals indicates the same indirectly [19, 22, 28].

In our experiments, we compared the reaction to 7-day continuous rotation (following the program described above) of intact animals and mice that were preconditioned to hypergravitation. Conditioning consisted of daily (5 times a week) rotation on a centrifuge at 2 G for 6 h. The results of these experiments are submitted in Table 2; analysis thereof indicates that, if 7-day continuous exposure to 2 G is preceded by 20-day conditioning, the above-described signs of hypergravitation stress (see Table 1) do not develop. Unlike intact animals, preconditioned mice exposed to 7-day rotation do not develop involution of the thymus, lymphopenia or severely retarded growth, i.e., the condition appears to remove the reaction to continuous rotation, a factor that we previously defined as hypergravitation stress.

It should be mentioned that the actual conditioning process is not indifferent to the organism and, although conditioned animals are not lagging from the control with respect to weight, they present such a typical sign of a stress reaction as lymphopenia at the early conditioning stage. This is followed by adaptation (manifested outwardly, in particular, by normalization of blood) which, however, should not be interpreted as a return to normal, but as a change to a new, stationary state, in which there is a basically different reaction to additional chronic stress than in intact control animals; "the substrate becomes established at a new level of equilibrium, with which the former stimulus ceases to stimulate or induce the former reaction."* It is expressly such conditioning that is the reason no difference can be demonstrated between the experiment and control, with regard to a number of vital parameters [22, 28] when the animals are examined after prolonged (months, years) rotation on a centrifuge.

In order to answer the question of correlation between specific and nonspecific components of the organism's reaction to altered gravitation and share of the nonspecific component of such reactions, the most adequate methodological procedure would be to compare the above-described reactions of the organism with the change from earth's gravity to 2 G (i.e., +1 G) to the reactions with the change to weightlessness.

In these two instances, the specific components of the reaction should be exact opposites, so that we can assume the existence of a distinctive scale of biological effects of changes in gravity per "upward" and "downward" unit, in relation to earth's gravity [35]. The nonspecific components of the reaction could be similar with hypergravitation and weightlessness, as is the

*Ukhtomskiy, A. A. in "Sobr. soch." [Collected Works], Vol 6, 1950, p 171.

case, for example, in the presence of hypoxia and hyperoxia, hypothermia and hyperthermia, etc.

Table 3 lists data we obtained from examining animals (male Wistar rats) after a 22-day flight on the Kosmos-605 satellite [36]. As can be seen in Table 3, the space flight conditions led to involution of lymphoid organs: decrease in weight of the thymus and spleen, as well as in number of thymocytes and splenocytes; lymphopenia was observed in blood; the experimental animals weighed less than controls, i.e., the changes were virtually analogous to the ones we observed with hypergravitation, which are illustrated in Table 1.

Control experiments conducted in order to differentiate between the effects of different components of the set of flight factors lead us to believe that the above-described effects are unrelated to either inflight maintenance conditions or the effects of extreme factors (vibration, linear and impact G forces) on the animals, and that they can be attributed to the stressor effect of weightlessness.

Thus, although a change in gravitation level constitutes a change to basically different living conditions for mammals adapted through evolution to 1 G, this change (both to weightlessness and hypergravitation) is primarily a similar stress factor for them as the factors they encountered in the course of evolution in their natural habitat (changes in air environment, temperature, etc.).

In weightlessness and hypergravitation, as is the case with other factors, nonspecific changes on the order of a stress reaction develop along with specific effects related to a change in load on the locomotion system, redistribution of blood, etc. [37, 38]. However, the share of the nonspecific component is considerable, and we cannot rule out the possibility that expressly this component determines most of the functional and structural changes occurring in the organism under such conditions.

Since animals referable to different levels of biological organization are characterized by different reactivity in adaptation and resistance to extreme factors [12, 14], it is logical to assume that the severity of nonspecific (stressor) changes in the presence of altered gravitation would vary in them, and this must be borne in mind when selecting experimental models and extrapolating the results from one animal species to another.

BIBLIOGRAPHY

1. Smith, A. H. in "Fundamentals of Space Biology and Medicine," Moscow, Vol 2, book 1, 1975, pp 141-176.

2. Hertwig, 1898 quoted by Korzhuyev, P. A. 1971 [16].

3. Thompson, D. "Growth and Form," Cambridge, 1917.

4. Brovar, V. Ya. "Gravity and Morphology of Animals," Moscow, 1960.

5. Isakov, P. K. in "Aviatsionnaya i kosmicheskaya meditsina" [Aviation and Space Medicine], Moscow, 1963, pp 220-226.

6. Korzhuyev, P. A. Ibid, pp 284-287.

7. Idem, in "Mediko-biologicheskiye issledovaniya v nevesomosti" [Biomedical Research on Weightlessness], Moscow, 1968, p 89.

8. Idem, "Evolution, Graviation and Weightlessness," Moscow, 1971.

9. Gazenko, O. G., and Gurdjian, A. A. in "Life Sciences and Space Research," Amsterdam, Vol 3, 1965, pp 241-257.

10. Salisbury, F. B. BIOSCIENCE, Vol 19, 1969, pp 407-410.

11. Danileyko, V. I. FIZIOL. ZH. [Physiological Journal--Ukrainian], No 5, 1971, pp 702-708.

12. Sirotinin, N. N. PAT FIZIOL. [Pathologicsa Physiology], No 5, 1961, pp 13-15.

13. Idem, FIZIOL. ZH., Vol 7, No 1, 1961, pp 3-8.

14. Idem, in "Kislorodnaya nedostatochnost'" [Hypoxia], Kiev, 1963, pp 3-13.

15. Pestov, I. D., and Geratevol', Z. Dzh. in "Osnovy kosmicheskoy biologii i meditsiny" [Fundamentals of Space Biology and Medicine], Moscow, Vol 2, Book 1, 1975, pp 324-369.

16. Baranov, V. I.; Gyurdzhian, A. A.; Lomova, M. A.; et al. in "Aviatsionnaya i kosmicheskaya meditsina," Moscow, 1963, pp 56-60.

17. Gyurdzhian, A. A.; Lomova, M. L.; and Radkevich, L. A. DOKL. AN SSSR [Reports of the USSR Academy of Sciences], Vol 151, No 4, 1963, pp 982-985.

18. Gyurdzhian, A. A., and Apanasenko, Z. I. Ibid, Vol 156, No 1, pp 225-227.

19. Gyurdzhian, A. A.; Apanasenko, Z. I.; Baranov, V. I.; et al. in "Vliyaniye ioniziruyushchikh izlucheniy i dinamicheskikh fakotorov na funktsii tsentral'noy nervnoy sistemy" [Effects of Ionizing Radiation and Dynamic Factors on Functions of the Central Nervous System], Moscow, 1964, pp 48-59.

20. Bengele, H. H. AM. J. PHYSIOL., Vol 216, 1969, pp 659-665.

21. Burton, R. R., and Smith, A. H. PROC. SOC. EXP. BIOL. (New York), Vol 128, 1968, pp 608-611.

22. Oyama, J., and Platt, W. T. AM. J. PHYSIOL., Vol 209, 1965, pp 611-615.

23. Idem, ENDOCRINOLOGY, Vol 76, 1965, pp 203-209.

24. Idem, AM. J. PHYSIOL., Vol 212, 1967, pp 164-166.

25. Smith, A H., and Burton, R. R. AEROSPACE MED., Vol 41, 1970, pp 1184-1186.

26. Vrabiescu, A., and Enachescu, G. Ibid, Vol 40, 1969, pp 1300-1304.

27. Wunder, C. C.; Lutherer, L. O.; and Dodge, C. H. Ibid, Vol 34, 1963, pp 5-11.

28. Wunder, C. C.; Briney, M. R.; and Skaugsted, C. NATURE, Vol 188, 1960, pp 151-152.

29. Wunder, C. C.; Meyer, F. N.; Clark, M. E.; et al. AM. J. PHYSIOL., Vol 221, 1971, pp 559-563.

30. Savina, Ye. A., and Podymov, V. K. KOSMICHESKAYA BIOL. [Space Biology], No 1, 1972, pp 14-19.

31. Simakov, Yu. G.; Agafonov, V. A.; Volkova, O. V.; et al. ARKH. ANAT. [Archives of Anatomy], No 3, 1973, pp 5-12.

32. Gorizontov, O. D. VESTN. AMN SSSR [Vestnik of the USSR Academy of Medical Sciences], No 7, 1969, pp 23-34.

33. Idem, ARKH. PAT. [Archives of Pathology], No 8, 1973, pp 3-12.

34. Idem, PAT. FIZIOL., No 2, 1974, pp 3-6.

35. Gazenko, O. G., and Gyurdzhian, A. A. in "Problemy kosmicheskoy biologii" [Problems of Space Biology], Moscow, Vol 6, 1967, pp 22-42.

36. Il'in, Ye. A.; Serova, L .V.; and Noskin, A. D. KOSMICHESKAYA BIOL. , No 3, 1976, pp 9-14.

37. Gazenko, O. G.; Adamovich, B. A.; and Il'in, Ye. A. VESTN. AN SSSR [Vestnik of the USSR Academy of Sciences], No 9, 1975, pp 62-70.

38. Portugalov, V. V.; Savina, Ye. A.; Kaplanskiy, A. S.; et al. KOSMICHESKAYA BIOL., No 4, 1976, pp 19-25.

EXPERIMENTAL AND GENERAL THEORETICAL RESEARCH

UDC: 613.693

MAIN RESULTS OF MEDICAL RESEARCH CONDUCTED DURING THE FLIGHT OF TWO CREWS ON THE SALYUT-5 ORBITAL STATION

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian No 5, 1977 pp 33-41

[Article by N. M. Rudnyy, O. G. Gazenko, S. A. Gozulov, I. D. Pestov, P. V. Vasil'yev, A. V. Yeremin, V. A. Degtyarev, I. S. Balakhovskiy, R. M. Bayevskiy and G. D. Syrykh, submitted 25 Apr 77]

[Text] The 60th anniversary of the Great October Socialist Revolution coincides with the 20th anniversary of the launching of the first Soviet artificial satellite of earth. In this time, 39 Soviet cosmonauts have made 30 flights on spacecraft and orbital stations. Among the latest achievements in this field are the flights of two crews on the Salyut-5 orbital station in 1976-1977. The 49-day flight of cosmonauts B. V. Volynov and V. M. Zholobov, and the 18-day flight of V. V. Gorbatko and Yu. N. Glazkov were not longer than the periods man has spent in weightlessness in flights made in the USSR and United States; they did have a specific distinction, which is important from the standpoint of medical support of such flights. The program of both flights was of an extensive exploratory nature. It included many diverse studies directed toward solving scientific and national economic problems, and the crews were very determined to fulfill both the main and additional investigations. This created objective conditions for the cosmonauts to be exposed not only to the physical factors of the flights, but factors due to intensive activity.

At the present time, the armamentarium of ways and means of preventing the deleterious effect of weightlessness, as one of the main physical factors of space flight, is complete [1, 2], and it has yielded good results when tested during previous flights on orbital stations. On the Salyut-5 station, it included the following: space simulator for physical exercises (treadmill), weighted suit to be worn at all times, vacuum container for the lower half of the body, postflight preventive suit, onboard kit with a set of drugs.

Telemetry methods [3, 4], as well as radio communications and television observations were used for routine medical monitoring of the cosmonauts. The physiological parameters (EKG in the D-S lead, seismocardiogram, respiration rate and body temperature, EKG in 12 leads, vital capacity of the lungs,

pulmonary ventilation, sphygmogram, kinetocardiogram, tachyoscillogram, venous-arterial pulsogram, rheogram of the head) were recorded and relayed over the telemetry communication channel by means of onboard equipment, both at rest and with measured loads (4-min run on treadmill at the rate of 150-160 steps/min, lower body negative pressure LBNP]--25 mm Hg for 2 min and 35 mm Hg for 3 min). The medical research program provided for the following: taking and preserving samples of capillary blood for subsequent analysis on the ground, measurement of body mass, determination of threshold sensitivity of the vestibular system to galvanic current, gustatory sensibility (taste indicators), as well as a number of psychophysiological studies. Thus, not only could the changes due to physical flight factors (weightlessness) be effectively monitored, they could also be corrected.

In order to prevent any possible adverse changes related to the intensive work to fulfill the flight program, the following measures were provided: regulation of work and rest schedule, 8 h of continuous sleep, 3 meals, allocation of time for self-service and personal hygiene, physical training and rest.

According to the medical recommendations, the work schedule of the cosmonauts should constitute 42 to 48 h per week, with 1 day off, not counting the time required for the above measures intended to preserve a high degree of fitness and to regain strength. Maintaining the necessary comfortable conditions for living and work was also an important prerequisite for preservation of efficiency. The parameters of the gas environment, microclimate, lighting conditions and noise background were consistent with the prevailing physiological and hygienic standards. The caloric value of daily rations constituted 3000±100 kcal; a more diversified assortment of foods was provided than in the preceding flights (6 menus), and it was also possible to warm the tubes of food, cans and bread. There was refinement of the set of personal hygiene items and a greater variety of recreational items.

During the flights of the first and second crews, all of the biomedical equipment operated without malfunctions; however, the medical recommendations pertaining to work and rest schedule were not completely followed. This was due to an appreciable increase in labor to perform the main and additional work with concurrent decrease in time spent on eating, resting and exercising. On some days, the crews worked for 14-16 h, and this inevitably shortened the sleep period. Insufficient sleep was particularly typical of the first crew. The crews made only partial use of their days off. Such great selflessness resulted in successful fulfillment of the flight program; however, it did leave its mark on the cosmonauts' wellbeing and functional state. In most cases, the changes in wellbeing and appearance of objective functional changes in the crew members were related to the intensity of their work.

Results of Medical Investigations

According to the preflight clinical and physiological examination, the crew members were deemed to be in good health and fit for the space flight. Isolated

extrasystoles were periodically recorded in the preflight period for cosmonauts B. V. Volynov and Yu. N. Glazkov. V. M. Zholobov presented decalcification of the papilla of the renal pelvis, and V. V. Gorbatko periodically presented a transient decline of the S-T segment and T wave on the EKG, with no clinical manifestations or negative dynamics. Endurance of functional loads was evaluated as good or excellent.

In the powered segment of the flight, the maximum pulse rates (per min) were as follows: 100 in B. V. Volynov, 108 in V. M. Zholobov, 132 in V. V. Gorbatko and 84 in Yu. N. Glazkov. The process of initial adaptation to weightlessness of the first crew was associated with some changes in wellbeing, in particular, appearance of headache in the flight engineer; at this time, the second crew presented no changes referable to wellbeing and fitness. Objective signs of greater influx of blood to the head, with development of edema of soft facial tissues, were equally marked in all of the cosmonauts.

Subsequent changes in wellbeing of the first and second crews were the most distinctly determined by intensity of the work load, and they were often manifested by signs of fatigue, particularly toward the end of the work day. During the 18-day flight of V. V. Gorbatko and Yu. N. Glazkov, these signs were usually compensated by proper sleep, whereas in the longer flight of the first crew they were associated with gradual development of asthenization, particularly by some neuroemotional and vebetovascular manifestations. Thus, on the 25th day of the flight, the crew commander developed unpleasant sensations in the region of the heart, general weakness, excessive perspiration and arterial pressure elevation to 150/80 mm Hg, against the background of considerable lack of sleep (on the previous night, he had slept for only 3 h). Administration of sodium pentobarbital and subsequent sleep for 9 h eliminated these changes. Fatigue and asthenization in the flight engineer toward the end of the flight were associated with diminished appetite, headache toward the end of the work day and, in some cases, this required drug therapy (analgesics). The onboard medicine kit was also used for several other indications (edema of the nasal mucosa, minor trauma, inflammation of the nailbed, sleep disorders, constipation).

According to the results of routine [operational] medical monitoring, the changes in heart rate and elements of the EKG complex in the D-S lead were consistent both with the findings made prior to the flights and the distinctions observed in the preflight work-up on the cosmonauts. Thus, V. V. Gorbatko presented significant fluctuation of T wave amplitude, which occasionally dropped to 15-17 times less than the amplitude of the R wave. As we have already indicated, analogous changes were recorded on this cosmonaut prior to the flight. Yu. N. Glazkov developed isolated extrasystoles (3 during the first half of the mission and 9 in the second).

According to the results of statistical processing of dynamic series of R-R intervals (at least 100 intervals in each block), we analyzed the histogram characteristics: mode (Mo), mode amplitude (AMo), variational swing (ΔX) and tension index In = $A/2\Delta X Mo$. High In, indicative of considerable centralization of regulatory processes, were observed during lift-off and performance of important dynamic operations (for example, docking). In the evenings,

the values of In were higher than in the mornings, which was indicative of tension of regulatory mechanisms. In the first crew, high values of In were recorded on the 23d-26th flight days at night as well, and this was indicative of poor sleep. Higher values of In were observed in the commander of the second crew.

As in previous flights, the cardiovascular system and circulation as a whole were also the objects of in-depth medical examinations.

In most examinations during flight, end and lateral systolic arterial pressure was 15-20 mm Hg higher than the preflight levels in both crews (Table 1). V. M. Zholobov and Yu. N. Glazkov also presented 10-12 mm Hg elevation of mean dynamic pressure. As we know, after a period of acute adaptation there was normalization of arterial pressure of the crews of the Salyut and Salyut-4 orbital stations [3-6]; for this reason maintenance thereof on a high level should be interpreted as the result of great work and emotional tension. The stroke and minute volumes held at the maximum preflight levels during the flight, or else were above the latter. The pulse wave distribution rate (PWDR) in the aorta was also generally somewhat high, particularly in V. M. Zholobov. The dynamics of actual specific vascular resistance (ASR) were usually consistent with the change in cardiac output. Throughout the flight, blood pressure in the jugular vein also remained high in the commander and more so in the flight engineer of the first crew. As we know [7], it had normalized to a considerable extent, or was below the base level in the second crew of the Salyut-4 orbital station examined on the 43d-44th day of the flight. Signs of venous stasis were also observed, according to the results of focusing rheography, with electrodes situated in the fronto-occipital projection. In B. V. Volynov, the venous components of the rheographic curve were less marked on the 45th day than the 17th, whereas in V. M. Zholobov, on the contrary, they were more marked on the 45th day than on the 25th. Unlike the commander, who presented increased tonus of arterial vessels according to head rheograms, the flight engineer presented a significant decrease of tonus of arterial vessels by the end of the flight and this, along with the above-mentioned signs of venous stasis, appeared to be less favorable. Filling of jugular veins and blood pressure in them were also increased in V. V. Gorbatko and Yu. N. Glazkov. We did not take rheograms of their head region.

A complete electrocardiographic examination of B. V. Volynov on the 19th day of the flight in the left chest leads (V_4-V_6) revealed a 0.5-1.0 mm downward shift of the S-T segment, as well as flattening of the T wave, which acquired a symmetrical shape. These changes can also be evaluated as signs of metabolic disturbances in the myocardium [8-10]. These changes became more distinct on the 28th and 31st days of the flight. The EKG dynamics of the flight engineer warrant the belief that he had developed analogous disturbances in the myocardium by the end of the flight, although they were very negligible.

According to the reports of the cosmonauts, the functional test with LBNP were well tolerated during the flight; however, the effect appeared to be

stronger than on earth in a number of instances (Yu. N. Glazkov and V. V. Gorbatko). B. V. Volynov and V. V. Gorbatko presented a moderate cardiovascular reaction to LBNP: a maximum of a 22% increase in heart rate, 39% decrease in systolic blood volume, with no appreciable change in arterial pressure. V. M. Zholobov presented a distinct decrease in orthostatic stability, which increased toward the end of the flight. His heart rate was 64% higher during LBNP than in the initial position and systolic blood volume diminished by 63%.

Yu. N. Glazkov also presented a marked cardiovascular reaction to LBNP (on the 12th day of the mission). The heart rate increased by 45%. There was a decrease in peripheral vascular resistance and rate of distribution of the pulse wave over the aorta.

In most cases, the reactions of B. V. Volynov and V. M. Zholobov to the physical loads were moderate and did not change appreciably with increase in duration of the mission. Only on the 40th day did we record signs of diminished physical fitness in the flight engineer. During the 4-min running test, his heart rate increased by 87%; however, because of the severe decrease in systolic blood volume, there was no increase in minute output, as compared to the base level.

Examination of blood samples taken during the mission confirmed the increase in blood urea concentration observed in previous missions. There were no changes in phosphorus fractions of whole blood, and this could be interpreted as an indirect indication of unchanged level in blood of 2,3-diphosphoglyceric acid, which is of substantial importance in implementation of hemoglobin function.

For the first time in the Soviet Union, a study was made of the dynamics of change in body mass during space flight on the Salyut-5 orbital station.

The data listed in Table 2 indicate that the main loss of body mass, also recorded in American astronauts [11], occurs at the first stage of the space flight; these indices hold at a rather stable level thereafter. Apparently, the more marked changes in body mass of the members of the first crew are one of the manifestations of asthenization, which developed against the background of fatigue and insufficient sleep. Both the frequent headaches toward the end of the flight experienced by the flight engineer and the poorer appetite were also involved in the change in body mass.

During the mission, we observed decreased sensibility of the vestibular system to galvanic current in all of the cosmonauts (E. V. Lapayev); there was negligible change in gustatory sensibility of the tongue (V. Ye. Potkin).

Both crews performed about 50% of the planned exercises during the mission. Preventive exposure to LBNP for the last 3 days before landing was done in a shorter version only by the second crew. All of the preventive measures were well-rated by the cosmonauts; failure to perform the planned exercises was attributed to the shortage of time. The weighted suits to be worn at all times were used daily and also well-rated by the crew members.

Table 1. Dynamics of circulatory parameters in the first and second crews of the Salyut-5 orbital station

Crew members	Time of examination		HR, min	Arterial pressure, mm Hg				PWDR, m/s	SV, ml	MV, liters	ASR, arbitr. units
				minimum	mean	lateral	end				
B. V. Volynov	Before flight	2.5 months	54	53	81	103	129	6,8	103	5,6	28
		5 days	51	59	85	101	127	4,5	150	7,7	21
	During flight	6th day	47	54	96	119	146	6,3	157	7,3	26
		14th »	50	70	96	132	153	6,9	135	6,7	28
		16th »	48	63	94	125	140	6,1	160	7,4	25
		28th »	56	65	96	126	148	6,5	145	8,1	23
		44th »	53	67	92	121	147	7,0	118	6,3	28
V. M. Zholobov	Before flight	2.5 months	43	54	82	99	122	5,1	124	5,3	30
		5 days	42	46	71	87	104	4,5	136	5,7	24
	During flight	6th day	40	48	75	109	131	6,5	138	5,5	26
		7th »	41	48	72	100	132	6,6	121	5,0	28
		13th »	41	51	87	110	137	6,3	134	5,5	30
		21th »	55	48	—	98	130	6,0	128	7,0	—
		28th »	51	50	80	106	140	5,8	137	7,0	22
		40th »	53	42	75	100	122	5,2	166	8,8	17
		43th »	58	57	79	108	132	6,1	121	7,0	22
V. V. Gorbatko	Before flight	6 months	63	62	96	106	131	6,8	86	5,4	33
		3 days	78	69	94	108	146	6,3	83	6,5	25
	During flight	13th	69	62	92	109	151	6,2	106	7,3	21
Yu. N. Glazkov	Before flight	6 months	48	56	86	101	126	5,3	116	5,5	26
		5 days	55	59	86	98	134	5,6	99	5,45	26
	During flight	8th day	67	60	100	110	120	—	—	—	—
		12th "	74	57	100	115	147	—	—	—	—

Key: HR) heart rate
PWDR) pulse wave distribution rate in aorta
SV) stroke volume
MV) minute volume
ASR) actual specific resistance

Table 2. Decrease in body mass (kg) during mission

Crew members	Day of flight							
	4th	7th	13th	17th	21st	30th	34th	45th
B.V. Volynov	—	—	—5,34	—	—4,57	—	—6,19	—6,95
V.M. Zholobov	—	—	—2,94	—	—3,2	—2,75	—2,69	—4,42
V.V. Gorbatko	—1,61	—2,1	—2,67	—2,6	—	—	—	—
Yu.N. Glazkov	—2,24	—2,81	—2,59	—2,95	—	—	—	—

Postflight examination of the cosmonauts revealed signs of asthenization, fatigue and vegetative disturbances, which were more marked in the crew members who were on the 49-day mission.

As can be seen in Table 3, the changes in postflight body mass are quite consistent with the data recorded during the flight (see Table 2), although they were somewhat more marked.

Table 3. Changes in some anthropometric parameters and muscle tone after the mission

Crew members	Change in body mass, kg	Change in thigh circumference cm	Change in leg circum. cm	Decrease in tonus of leg muscles, arbitrary units
B.V. Volynov	—7,3	—5,7	—3,6	—20
V.M. Zholobov	—6,6	—3,9	—3,2	—8
Yu.N. Glazkov	—3,9	—1,5	—2,8	—38
V.V. Gorbatko	—3,5	—1,9	—2,3	—20

All four cosmonauts presented decreased orthostatic stability after the mission; however, in the flight engineer of the first crew, endurance of vertical position deteriorated the most, so that the test was stopped 1 min after changing to vertical position on the 1st day and 5 min after, on the 2d day. Orthostatic stability was essentially restored in all crew members 2 weeks after the mission.

Greater strain was involved in performance of measured physical exercise on the bicycle ergometer (600 kg-m/min for 7 min) than in the preflight period. On the 3d postflight day, maximum pulse rate increased by 13% more than in the preflight functional test in B. V. Volynov, 23% in V. M. Zholobov, 8% in V. V. Gorbatko and 4.6% in Yu. N. Glazkov. In the first crew, worsening of the reaction to the physical load was also manifested by an increase in pulmonary ventilation, decrease in "oxygen pulse," slower recovery processes and signs of diminished contractility of the left ventricle. These changes were considerably less marked in the second crew.

The postflight clinical and laboratory work-up on the crews of Salyut-5 revealed essentially the same changes as were observed previously in other crews of orbital space stations [3, 12-14], but they were more marked in the first crew (B. V. Volynov and V. M. Zholobov). Thus, the engineer presented more cellular elements and albumin in urine on the first few postflight days than all previously examined cosmonauts. Casts were demonstrated in some urine samples, and this was indicative of some irritation of renal tissue, which was not observed previously.

All crew members presented metabolic changes that were typical of the postflight period: retention of water and salts (in the water load test also), increased excretion of epinephrine, norepinephrine, as well as (on some days) aldosterone, to the top range of normal. Excretion of 17-hydroxycorticosteroids was in the usual range, but the proportion of different fractions was changed; there were no marked changes in the nitrogen components. Blood lipid content diminished slightly after the mission; there was an increase in activity of creatine phosphokinase and sorbitol dehydrogenase; there was a change in microflora in the direction of simplification against the background of an increase in number of conditionally pathogenic strains, which was indicative of some decrease in immunity.

Table 4. Change in hemoglobin mass, number of reticulocytes and bromine space

Index	Meas. unit	B.V. Volynov	V.M. Zholobov	V.V. Gorbatko	Yu.N. Glazkov
Decrease in hemoglobin mass during flight	g	—247	—241	—105	—101
	%	—32	—34	—14	—14
Reticulocytes, thou/µl:					
before flight		40	40	50	40
1st postflight day		24	28	24	20
6th "		47	127	82	67
Change in bromine space	liter	—0,2	+0,7	+0,6	—1,1
	%	—1	+5	+4	—7

As can be seen in Table 4, there were no consistent changes during the mission in magnitude of extracellular (bromine) space, but the hemoglobin mass dropped, particularly in the first crew, and there was a decrease in number of reticulocytes. Immediately after landing, the decrease in mass did not affect hemoglobin concentration in blood, but then there was an increase in number of reticulocytes, while the hemoglobin concentration decreased. In the first crew, there was almost 3 times greater decrease in hemoglobin mass than in the second; accordingly, the increase in number of reticulocytes lasted longer and reached 150,000-170,000 per µl on the 15th postflight day. In this regard, it may be assumed that, during weightlessness, there was a decrease in rate of hemoglobin synthesis, with corresponding decrease in mass of circulating blood. During the readaptation period, we observed reactive increase in rate of synthesis of hemoglobin and plasma

proteins; however, the latter recovered sooner. Analogous findings were made on the Skylab crew [15, 16].

Thus, the results of the medical studies conducted on the Salyut-5 orbital station confirmed many of the findings of previous missions and yielded new data characterizing reactions of the organism to physical flight factors and intensive work.

The previously made conclusion that there is an appreciable change in functional systems under the influence of weightlessness should be considered valid on the whole. In view of the decreased reserve capabilities of the organism and relatively long adaptation period, strict adherence to work and rest regimen of cosmonauts is mandatory. All of the planned exercises must be performed to prevent the deleterious effects of weightlessness.

The phenomenon of redistribution of blood, the state of capacity and resistance vessels, as well as cerebral circulation require continued in-depth and comprehensive investigation.

BIBLIOGRAPHY

1. Vasil'yev, P. V. in "Nevesomost'" [Weightlessness], Moscow, 1974, pp 278-298.

2. Genin, A. M., and Pestov, I. D. in "Chelovek v kosmose" [Man in Space], Moscow, 1974, pp 76-87.

3. Vorob'yev, Ye. I.; Gazenko, O. G.; Gurovskiy, N. N.; et al. KOSMICHESKAYA BIOL. [Space Biology], No 1, 1976, pp 15-22.

4. Degtyarev, V. A.; Doroshev, V. G.; Kalmykova, N. D.; et al. Ibid, No 2, 1974, pp 34-42.

5. Degtyarev, V. A.; Popov, I. I.; Batenchuk-Tusko, T. V.; et al. in "Nevestomost'," Moscow, 1974, pp 132-157.

6. Doroshev, V. G.; Batenchuk-Tusko, T. V.; Lapshina, N. A.; et al. KOSMICHESKAYA BIOL., No 2, 1977, pp 26-31.

7. Yuganov, Ye. M.; Degtyarev, V. A.; Nekhayev, A. S.; et al. Ibid, pp 31-37.

8. Kedrov, A. A. TER. ARKH. [Therapeutic Archives], No 12, 1965, pp 16-19.

9. Kechker, M. I. "Electrocardiograms in Hypertrophy of the Atrial and Ventricular Myocardium," Moscow, 1970.

10. Fel'dman, S. B. "Early Detection of Cardiac Insufficiency," Moscow, 1976.

11. Buchanan, P. AVIAT. SPACE ENVIRONM. MED., Vol 47, 1976, pp 413-418.

12. Beregovkin, A. V.; Krupina, T. N.; Syrykh, G. D.; et al. KOSMICHESKAYA BIOL., No 2, 1977, pp 19-22.

13. Grigor'yev, A.I.; Kozyrevskaya, G. I.; Natochin, Yu. V.; et al. in "Kosmicheskiye polety na korablyakh 'Soyuz'" [Space Missions on the Soyuz Series of Spacecraft], Moscow, 1976, pp 266-303.

14. Berry, Ch. AVIAT. SPACE ENVIRONM. MED., Vol 47, 1976, pp 418-424.

15. Kimzey, S. L.; Johnson, P. C.; et al. Ibid, pp 383-390.

16. Leach, C. S.; Johnson, P. C.; and Rambaut, P. C. Ibid, pp 402-410.

UDC: 612.015.31+612.46]-06:629.78

DISTINCTIONS OF FLUID AND ELECTROLYTE METABOLISM AND RENAL FUNCTION IN CREW MEMBERS OF THE FIRST SALYUT-4 EXPEDITION

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian No 5, 1977 pp 41-47

[Article by A. I. Grigor'yev, G. I. Kozyrevskaya, B. R. Dorokhova, V. I. Lebedev and B. V. Morukov, submitted 28 Jun 76]

[Text] Examination of cosmonauts following missions on the Soyuz program revealed substantial changes in fluid-electrolyte metabolism and systems that regulate kidney function [1-6]. With increase in duration of missions, some new, qualitatively different changes appeared, which were probably due to the increased significance of weightlessness in the genesis of these disorders [4, 5]. Our objective here was to investigate the distinctions of fluid-electrolyte metabolism, osmoregulatory and ionoregulatory functions of the kidneys in cosmonauts A. A. Gubarev and G. M. Grechko after their 30-day orbital flight on the Salyut-4 station.

Methods

We tested fluid-electrolyte metabolism and renal function before (Nov 74 and 3-5 Jan 75) and after (9-14 Feb and 10 and 27 Mar 75) the mission. Urine was analyzed in fractions. During the mission, G. M. Grechko collected urine on 2 days (14 Jan and 6 Feb 75) in containers with a specific amount of lithium acetate, and diuresis was evaluated according to dilution of the latter. Urine samples were delivered to earth in polyethyelene containers, which also contained hydrochloric acid to prevent precipitation of calcium and magnesium salts.

Venous blood for biochemical tests was taken before the mission, as well as on the 1st, 7th and 30th days after it.

The water load test (20 ml/kg body weight) was performed on the 2d postflight day to evaluate renal function. Urine was collected every 30 min for 2.5 h. Sodium and potassium (flame photometry method), calcium and magnesium (spectrophotometry on an atomic absorbtiometer), creatinine (Popper method) and osmotic concentration (cryoscopy method) were assayed in each urine and blood sample. Calculation was made of a number of indices characterizing

osmoregulatory and ionoregulatory functions of the kidneys, the physiological significance of which has been described in previously published works [3, 4]. We kept a record of daily fluid intake and body weight during the work-up period. On some days, we recorded fluid content of the food ration and determined its mineral composition.

Results and Discussion

Preflight examination of A. A. Gubarev and G. M. Grechko revealed that the electrolyte concentration in blood serum and excretion thereof in urine collected 1 day before and after a water load were at typical levels for healthy individuals in the same climate conditions and on an analogous diet.

Immediately after the 30-day mission, as was the case following shorter ones, both cosmonauts presented decreased diuresis (Table 1), as compared to the preflight level, whereas fluid intake increased significantly. As a result, on the day they landed and 1st postflight day, fluid intake was 2.1 ℓ greater than output by the kidneys in A. A. Gubarev and 2.7 ℓ greater in G. M. Grechko (Figure 1 and Table 1). On the basis of these data, as well as dynamics of recovery of body weight in the postflight period (see Figure 1), it may be assumed that the weight loss occurring during the 30-day mission was largely due to fluid loss. Slower recovery thereof to the base level in the flight engineer was apparently related to greater loss of muscle mass during the flight as a result of less intensive exercise.

Table 1. Renal excretion of fluid (ml), electrolytes (meq) and osmotically active substances (in mosm) before, during and after mission

Time of examination	Diuresis	Na	K	Ca	Mg	Osmotic. active substances
A. A. Gubarev						
Before flight ($M \pm m$)	1573±162	233±9,3	81±12,6	18,6±2,2	7,7±1,7	1277±56
After " 0 day 9 Feb	550	76	22	11,1	4,7	503
1st " 10 "	2205	123	30	27,0	8,7	1102
2d " 11 " *	3012	232	71	30,2	7,8	1160
3d " 12 "	2230	268	55	33,5	9,6	1181
4th " 13 "	1875	214	79	29,1	7,7	1122
5th " 14 "	2510	263	79	26,0	7,4	1259
G. M. Grechko						
Before flight ($M \pm m$)	1354±59	201±18,1	73±10,4	14,6±1,8	10,6±1,3	1156±82
During " 14 Jan	1390	213	71	7,0	7,7	1202
" 6 Feb	1560	220	84	31,0	15,0	1408
After " 0 day 9 Feb	555	80	24	8,9	5,3	499
1st " 10 "	778	76	41	18,3	10,4	709
2d " 11 " *	2690	148	71	17,5	7,8	1107
3d " 12 "	1590	166	55	14,2	8,1	919
4th " 13 "	1570	188	71	20,7	9,0	1099
5th " 14 "	1165	180	63	16,0	8,2	1130

*Water load test performed.

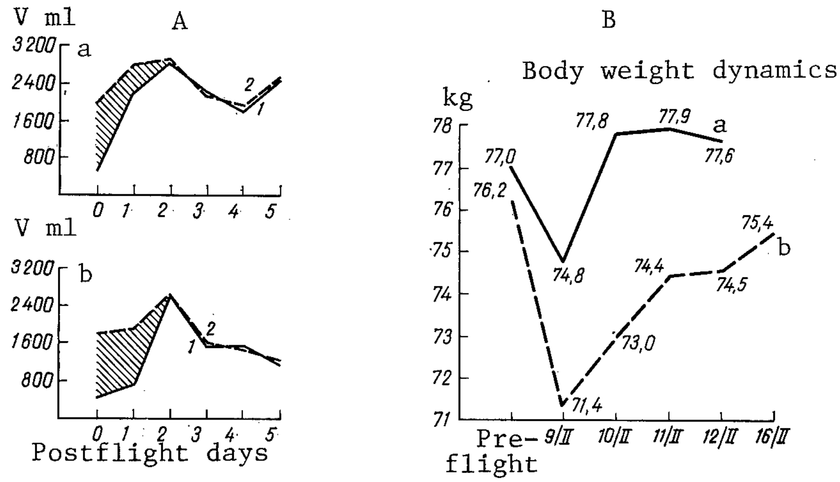


Figure 1. Diuresis and fluid intake (A), dynamics of recovery of body weight (B) in A. A. Gubarev (a) and G. M. Grechko (b) after 30-day mission. Solid line, diuresis; dotted line, fluid intake

In addition to decreased renal excretion of fluid after the mission, as compared to the preflight period, we observed decreased excretion of sodium, potassium and osmotically active substances in urine (see Table 1). As a rule, in the case of diminished diuresis, elimination of the same amount of electrolytes is obtained by an increase in concentration thereof in urine. After the mission, in spite of decreased diuresis, the concentration of sodium and potassium in urine and its osmolarity were substantially lower than in the preflight period, i.e., there was a change in normal correlation between level of diuresis and electrolyte concentration in urine. A similar phenomenon was also observed previously, following 2-8-day missions, but it was less marked. It may be assumed that in the course of a long-term space mission, the organism loses more minerals, including sodium and potassium, than fluid. Indeed, in the urine samples collected by G. M. Grechko during the mission, the sodium content was higher than in the background period, in both samples, and potassium content was higher in the second sample (see Table 1). Intake of salts with food decreased during the mission. Evidently, this is why there was more marked retention of sodium and potassium in the postflight period than retention of fluid. It took 4-5 days for recovery of the usual correlations between volume of urine and its osmotic concentration, whereas such recovery occurred within 1-2 days after brief missions.

There was a different correlation between level of diuresis and concentration in urine of bivalent ions, calcium and magnesium. Already in the first samples of urine taken after the mission, as well as in its final stage, there was a high level of these electrolytes (see Table 1). For this reason, excretion of calcium and magnesium was high during the period of the postflight examination. In the craft commander, excretion of calcium remained

high even on the 5th postflight day. Evidently, such marked hypercalciuria was due not only to the length of the mission, but relatively high individual intake of calcium because of the dietary distinctions, also noted in the preflight period.

After the flight, there was a substantial change not only in excretion of electrolytes in urine, but levels thereof in blood serum (Figure 2).

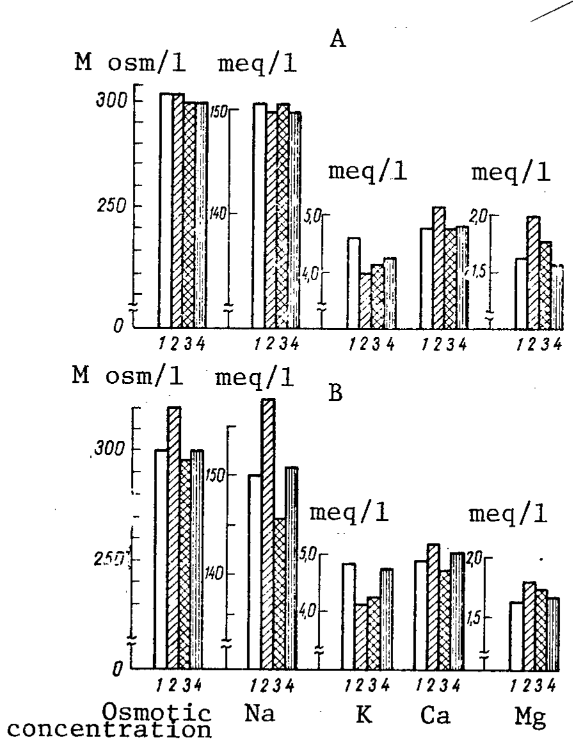


Figure 2.
Concentration of electrolytes and osmotically active substances in blood serum of A. A. Gubarev and G. M. Grechko before and on different days after the mission
1) preflight
2-4) 1st, 7th and 30th postflight days

On the 1st day after landing, both cosmonauts presented a 12 and 13% decrease in potassium concentration in blood serum and an increase in calcium and magnesium (see Figure 2). G. M. Grechko also presented a higher concentration of sodium and osmotically active substances. On the 7th postflight day, there was virtually complete recovery of most tested indices to base levels, and only the concentration of potassium remained below the preflight level in both cosmonauts. Subsequent analyses revealed that the potassium concentration had virtually reached the base level.

The water load test was performed on the 2d postflight day for special investigation of osmoregulatory and ionoregulatory renal function. By this time, the weight of A. A. Gubarev had returned to the base level, while 38% of the lost weight was not regained by G. M. Grechko. This was indicative of virtually complete replenishment of the initial amount of fluid in the body. However, the water load test revealed significant decrease in renal

excretion of fluid in both cosmonauts (Table 2 and Figure 3) due to diminished capacity of the kidneys for osmotic dilution of urine. In both the commander and flight engineer, maximum diuresis decreased by almost 50%, as compared to the findings of preflight tests (Table 3). It must be noted that there was also a significant decrease in clearance of osmotically free fluid during the period of maximum diuresis (see Table 3). This was associated with an increase in osmotic concentration of urine.

Table 2. Excretion of fluid (ml and %), electrolytes (Meq) and osmotically active substances (Mosm) 2.5 h after water load

Cosmonaut	Time of examination	Diuresis	Fluid output, % of intake	Na	K	Ca	Mg	Osmotic substances
A.A. Gubarev	Bef. flight	1324	82	27,8	13,1	1,56	0,47	161
	After "	732	47	12,8	4,7	2,82	0,86	123
G.M. Grechko	Bef. "	1250	83	21,1	11,6	0,69	0,32	156
	After "	555	37	6,75	3,5	1,63	0,75	105

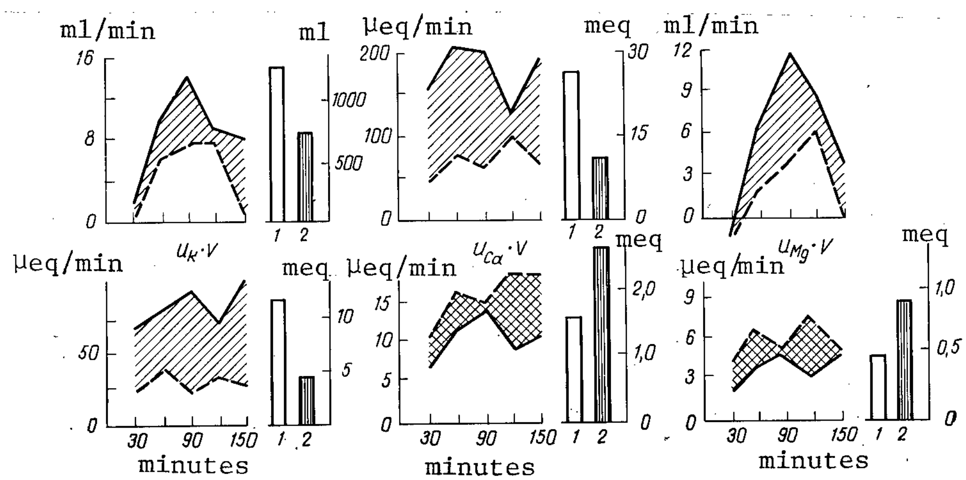


Figure 3. Rate of renal excretion of fluid and electrolytes during water load test in A. A. Gubarev before (solid line) and after (dotted line) mission. Excretion of fluid and electrolytes per test is shown in the columns: 1) before flight; 2) after flight

Table 3. Concentration (I, in Meq/ℓ, mosm/ℓ) and rate of excretion (II, μeq/min, μosm/min, ml/min) of electrolytes, osmotically active substances and fluid during the period of maximum diuresis following water load

Cosmonaut	Time of exam.	Diuresis, ml/min	Osmotic free liq. clearance	Na		K		Ca		Mg		Osmotic substances	
				I	II	I	II	I	II	I	II	I	II
A.A. Gubarev	Before flight	14,2	11,3	15,6	222	6,9	98	1,0	14,2	0,3	4,3	60	852
	After flight	7,7	5,4	13,1	101	4,3	33	2,9	22,3	0,95	7,3	102	785
G.M. Grechko	Before	12,8	9,9	17,7	227	7,2	95	0,45	5,8	0,15	1,9	68	870
	After	6,45	4,2	7,7	50	4,3	28	1,55	10,0	0,75	4,8	106	684

Analysis of these changes in renal function revealed that there was no decrease in glomerular filtration in both cosmonauts, as compared to preflight findings. This warranted the belief that the cause of diminished diuresis is not a decrease in filtration load, but an increase in reabsorption of fluid in the renal tubules. In view of the fact that, during the period of maximum diuresis, there was a significant decrease in excretion of osmotically free fluid and concentration of sodium in urine, it may be assumed that the changes in osmoregulatory renal function observed after the 30-day mission were due primarily to increased reabsorption of fluid in the distal segment of the nephron. Permeability of the walls of the distal and collecting tubules to fluid may increase under the influence of antidiuretic hormone (ADH), in the presence of an inadequate corticosteroid level, change in concentration of potassium and calcium in blood serum. The findings of the tests on the cosmonauts enabled us to rule out a decrease in activity of the adrenal cortex. The demonstrated changes in electrolyte composition of blood--hypokalemia and negligible hypercalcemia--lead to a decrease in permeability to water of renal tubules, rather than an increase [7-9]. For this reason, it may be assumed that the rather high postflight level of ADH secretion is the cause of diminished renal excretion of osmotically free fluid. Thus, according to the data of L. N. Ivanova, ADH of blood was 3-4 times higher than the usual levels after this mission in both cosmonauts, just before the water test. For this reason, the standard water load after the mission did not, apparently, completely diminish the high ADH secretion, and its level in blood remained relatively high.

Along with diminished diuresis, the water test revealed diminished excretion of sodium and potassium, as compared to the base levels (see Table 2 and Figure 3). As was the case in the first postflight urine samples, there was more marked decrease in excretion of sodium and potassium than fluid. This

was more marked during the period of maximum diuresis, when the diminished renal excretion of fluid was associated with a decrease, rather than increase, in concentration of sodium and potassium in urine, and this, of course, led to a marked decrease in rate of excretion thereof (see Table 3).

One of the most important findings of the test with the water load is the increased renal excretion of calcium and magnesium (see Table 2 and Figure 3). At peak diuresis following the water load, there was a significant increase in concentration of these electrolytes (see Table 3). At this time, there was an increase in calcium and magnesium excretion in urine, in spite of the diminished diuresis. A higher level of calcium excretion, as compared to the base period, was also observed in A.G. Nikolayev and V. I. Sevast'yanov after their 18-day mission. However, in the Soyuz-9 crew members, the increased excretion of calcium following the water load was associated with increased excretion of fluid and sodium, against the background of restored volume of intravascular fluid. The higher excretion of bivalent cations in the water test following the 30-day mission could have occurred as a result of an increase in filtration charge thereof due to an increased concentration of calcium and magnesium in blood serum, on the one hand, and as a result of decreased reabsorption thereof in the renal tubules, on the other.

At the present time, it is difficult to offer a complete explanation for the impaired correlation of activity of the osmoregulatory and ionoregulatory systems and the dissociation, demonstrated mainly in the water load test, in renal excretion of different ions, since the specific physiological mechanisms of these phenomena remain unknown in many respects. The observed changes in ion composition of blood, and particularly the changes in concentration of potassium, calcium and magnesium in it, might be one of the causes of impaired electrolyte transport in the kidneys after the mission. Probably, they alter the intracellular ion content, sensitivity of cells to hormones and mediators, as well as secretion and reabsorption of electrolytes in the renal tubules.

Investigation of renal function after the 30-day orbital flight revealed that, unlike short missions when most changes were referable to regulation of sodium and chlorides, the main osmotically active electrolytes of extracellular fluid, after the long-term flight substantial changes were also demonstrated in renal excretion and blood levels of potassium, calcium and magnesium. The disturbances referable to protein metabolism, which have been observed in the case of long-term missions [2, 10], warrant the belief that with prolonged weightlessness the metabolic changes become more marked and determine the postflight changes in renal function. Probably the changes in renal function following brief flights (up to 5 days) are related primarily to hemodynamic disturbances, while in the case of the 30-day mission they were the consequence of metabolic changes that occurred during the flight.

BIBLIOGRAPHY

1. Balakhovskiy, I. S.; Grigor'yev, A. I.; Dlusskaya, I. G.; et al. KOSMICHESKAYA BIOL. [Space Biology], No 4, 1971, pp 37-43.

2. Balakhovskiy, I. S., and Natochin, Yu. V. "Metabolism Under the Extreme Conditions of Space Missions and Simulation Thereof," Moscow, 1973, p 212.

3. Grigor'yev, A. I. FIZIOL. ZH. SSSR [Physiological Journal of the USSR], No 6, 1972, pp 828-835.

4. Grigor'yev, A. I., and Kozyrevskaya, G. I. KOSMICHESKAYA BIOL., No 5, 1970, pp 55-59.

5. Kozyrevskaya, G. I.; Natochin, Yu. V.; Grigor'yev, A. I.; et al. in "Kosmicheskaya biologiya i aviakosmicheskaya meditsina" [Space Biology and Aerospace Medicine], 4th, Summaries of Papers Delivered at All-Union Conference, Moscow--Kaluga, Vol 1, 1972, pp 259-260.

6. Natochin, Yu. V.; Kozyrevskaya, G. J.; Grigoryev, A. J.; et al. ACTA ASTRONAUT., Vol 2, 1975, pp 175-188.

7. Francois, G., et al. "Le Potassium. Aspects Physiologiques et Pathologiques," Paris, 1973.

8. Kleinzeller, A.; Krotkova, A.; and Nedvidkova, J. J. GEN. PHYSIOL., Vol 51, 1968, Pt 2, pp 326-334.

9. Schuck, O., and Cort, J. H. CANAD. J. PHYSIOL. PHARMACOL., Vol 46, 1968, pp 275-280.

10. Whedon, D. G.; Reid, J.; Lutwak, L.; et al. in "Cospar Meeting, 18th," abstracts, Sofia, 1975, p 88.

UDC: 616.12/.14-072.2-092.6

TECHNIQUE FOR SELECTIVE CATHETERIZATION OF THE HEART AND GREAT VESSELS USED IN BIOMEDICAL STUDIES OF HEALTHY INDIVIDUALS

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian No 5, 1977 pp 47-51

[Article by O. G. Gazenko, V. I. Shumakov, Yu. M. Volynkin, B. I. Shal'nev, L. I. Kakurin, V. M. Mikhaylov, V. Ye. Katkov and V. V. Chestukhin, submitted 25 Apr 77]

[Text] The biomedical research conducted in accordance with the Soyuz, Salyut, Apollo and Skylab programs revealed that continued investigation of the fine mechanisms of maintenance of circulatory homeostasis in man in a state of real or simulated weightlessness is one of the main directions of development of space medicine in the next few years [1, 2]. A purely physical phenomenon, absence or severe decrease in fluctuations of the hydrostatic component of blood pressure, plays the most important role in etiology of functional changes in many systems under such conditions. It is generally believed that the consistent response to the latter is redistribution of blood with increased influx thereof to the organs and parts of the body above the level of the heart, which is unusual under terrestrial conditions, followed by development of compensatory processes involving neuroreflex, metabolic and myogenic mechanisms. The problem of gravitation-related redistribution of blood, which has been the subject of particularly intensive investigation in recent years, is unclear in many respects, but it is quite obvious that it plays a role in development of the science dealing with circulatory disorders.

The redistribution process is referable primarily to the low pressure circulatory system, the vessels of which, that present dissimilar elasticity, contain about 80% of the entire blood volume. In the case of formation of a different hemodynamic status, which arises against the background of lack of fluctuations of the hydrostatic component of blood pressure, redistribution of blood will definitely elicit changes in venous pressure, the direction and severity of which are, however, unknown.

It may be assumed that, in weightlessness, venous pressure will change differently in different vascular regions, particularly because of the "waterfall" phenomenon [3]. For this reason, qualitative changes in this index in the

external jugular vein, a region which is the most accessible for studies in real weightlessness, apparently cannot reflect changes in pressure in other parts of the vascular system, for precise recording of which methods of selective catheterization are required.

Such techniques permit not only exact recording of pressure in different parts of the vascular system, but obtaining blood samples flowing from various organs, and biochemical analysis of such samples makes it possible to determine indirectly the level and distinctions of their metabolic activity. It is known that, even at rest, this activity is not the same, as indicated by the fact that the arteriovenous difference for oxygen constitutes about 11, 6 and 1 vol.% for the heart, brain and kidneys, respectively, whereas in mixed venous blood this index constitutes approximately 3.7 vol.% [4].

In this regard, it may be assumed that, in a number of instances, the metabolic changes in different organs may not be adequately reflected in mixed venous blood. Such a situation can occur, for example, in the case of varidirectional or dissimilarly marked metabolic changes, that do not exceed the "normal" range in various organs. In this case, analysis of the results, based on indices of mixed venous blood alone could lead to the fallacious conclusion that the organism does not react to a given factor. The situation is made even more complicated by the fact that, in such analysis, pulmonary function other than that pertaining to exchange of gases (metabolic) is totally overlooked, while the lungs participate in regulating the concentration of many indices [5]. It is apparent that examination thereof only in peripheral (from the ulnar vein) blood diminishes even more the informativeness of biochemical studies.

On the basis of the foregoing, it may be assumed that the use of selective catheterization is also desirable in the study of gravitation effects on the human body. In this regard, it is of particular interest to identify the organs of a healthy individual that are the most susceptible to the deleterious effect of factors that simulate weightlessness. There has not been such formulation of the problem previously in the literature. At the same time, its solution would not only yield a more distinct idea about the genesis of changes in various parts of the cardiovascular system during space flights and offer pathogenetically more substantiated means of preventing them, but, perhaps, to find a certain analogy to such changes in clinical practice on the organic level.

In order to solve such problems, one must use techniques of selective catheterization of the heart and great vessels, for the following basic considerations: 1) catheterization is the only technique available at the present time for penetrating into the human internal environment that is relatively safe and minimally traumatic; 2) it is only with this technique that one can assess the role of different organs and their interaction in maintaining homeostasis in man under normal and pathological conditions, and with exposure to extreme factors; 3) clinical knowhow (particularly referable to extreme states) has shown that indirect methods of examination do not always by far

furnish accurate information about hemodynamics; 4) biochemical tests of peripheral venous blood do not always permit evaluation of metabolism in the organism in general and contribution of different organs in particular, or to predict impairment of homeostasis; 5) at the present time, comparison of indirect and direct methods of examination of healthy individuals is still a burning issue. The answer to this question would permit evaluation, in many respects, of the informativeness of indirect techniques in situations where it is not yet feasible to use direct methods.

However, catheterization of the heart and great vessels is not only the principal technique in clinical physiology of circulation; it is also a surgical intervention, and this involves a number of distinctions that must be taken into consideration when using it. In the first place, they include the possibility of various groups of complications and effects on the emotional status of the subjects [6, 7].

The complications that could arise with catheterization of the heart and vessels are related primarily to the following factors: region of catheterization, duration thereof and intensity of manipulations [6, 8-10]. Analysis of results obtained in clinical practice shows that the danger of serious complications in healthy volunteers can be avoided almost entirely by adhering to the following conditions: meticulous screening of subjects, special preparation thereof, selection of appropriate (nontraumatic) catheterization technique, constant monitoring of the subjects' condition, continuous monitoring of the position of the catheter (using roentgenotelemonitors) and use of catheters with minimal possibility of thrombosis.

The possible changes in emotional status of the subjects should also not serve as a reason for restricting the use of this technique, since it has been demonstrated that the results obtained from a second (after simulated weightlessness) catheterization of male volunteers were correct and comparable [11]. Moreover, it is known that, during a flight and particularly during powered flight, a cosmonaut experiences considerable emotional tension. For this reason, in ground-based model experiments, one should specially create various stress situations for more complete simulation of space flight conditions, and investigate the functional state of the organism against the background of such situations, particularly since one can demonstrate gravitation disturbances more vividly under these conditions [11].

Because of the great informativeness and reliability of the technique of catheterization of the heart and great vessels, for the development of which the team of authors, Richards, Cournand and Forssman, received the Nobel Prize, it has found wide application, not only in clinical practice, but biomedical research pursued in the United States, Sweden, FRG and Japan, with the participation of healthy volunteeers, athletes, pilots and astronauts [7, 11, 12-21]. This research pursues primarily two goals: investigation of gravitational aspects of circulation and resolving problmes of occupational fitness. In the former case, cardiac catheterization is performed in the presence of exposure to G forces on a centrifuge, as well as following pharmacological "desympathization" and "denervation" of the heart,

hypokinesia, immersion in water and functional load tests; in the latter case, catheterization of the heart is combined not only with load tests, but selective coronarography. That the latter is used widely is indicated by the fact that in the period between 1971 and 1975 alone, 425 catheterizations of the left ventricle, combined with coronary angiography, were performed on pilots in the U. S. Air Force at the Brooks School of Aerospace Medicine (Texas) [21]. Some authors believe that preference should be given to the results obtained from direct investigative techniques to solve controversial problems pertaining to continuation of professional activity in aviation [19, 21].

Catheterization of the heart and great vessels is used in many clinics of the USSR to solve problems of pathological physiology of circulation and for accurate detection of disturbances thereof; however, it had not been used previously on a regular basis in biomedical research with the participation of healthy volunteers. At the present time, we have begun a series of studies of the gravitation effects on circulation and metabolism of various organs of healthy man, using selective catheterization of the heart and great vessels in pursuit of the goals and objectives of aerospace and clinical medicine. Work conducted in this direction provides for the following: 1) determination of the feasibility of clinical simulation of hemodynamic and metabolic changes that could occur in various organs and tissues during weightlessness; 2) development of pathogenetically substantiated agents for the prevention of its deleterious effects; 3) substantiation of some specifications for development of artificial organs, the function of which would be as close as possible to the function of a healthy man's natural organs.

The research began with a study of the effect of brief antiorthostatic hypokinesia, simulating the "acute" period of adaptation to weightlessness, on circulation and metabolism of various organs in a healthy man. As we know, this period is particularly important in the case of brief space missions or missions on orbital stations, since it is expressly at this time that a spacecraft docks with an orbital station, with the crew being transferred, and this is when equipment is prepared for operation, etc. At the same time, during this period the process of gravitational redistribution of blood is the most marked and there are vivid symptoms of motion sickness. Moreover, investigation of the "acute" period furnishes information as well about adaptation to longer weightlessness, since "immediate and long-term adaptation are not two different phenomena, but two stages of the same process that provides for reliable adaptation of the organism as a whole and the heart in particular to environmental demands" [22].

Selective catheterization of the veins of various organs--brain, lungs, liver, kidneys, osteomuscular sections of the lower extremities and heart-- was performed before and after 5 days of strict bed rest on healthy male volunteers. Biochemical analysis of incoming (arterial) and outgoing blood enabled us to make an indirect evaluation of metabolic changes. Considerable attention was given to the dynamics of pressure in capacity vessels of the systemic and pulmonary circulatory systems. The main indices of central and

intracardiac hemodynamics were recorded not only at rest, but during functional load tests: passive orthostatic and measured physical loads.

The different organs can be listed in the following order, according to severity of biochemical changes in blood flowing from them: brain, heart, liver, kidney and skeletomuscular block of the lower extremity. Evidently, these distinctions of individual organic reactions (primarily those of the brain and heart) during the period of "acute" adaptation must be taken into consideration in developing preventive agents and assessing their effectiveness.

Thus, the data in the literature and the results of our investigation indicate that selective catheterization of the heart and great vessels is very informative, and use thereof is desirable for the study of the effects of gravitational factors on the healthy human body. The obtained results will be submitted in detail in future publications.

BIBLIOGRAPHY

1. Gazenko, O. G.; Kakurin, L. I.; and Kuznetsov, A. G. (editors) "Space Missions on Soyuz Spacecraft," Moscow, 1976.

2. Gurovskiy, N. N., and Yegorov, A. D. KOSMICHESKAYA BIOL. [Space Biology], No 6, 1976, pp 3-14.

3. Duomareo, J., and Rimini, R. AEROSPACE MED., Vol 41, 1970, pp 175-178.

4. Wage, O., and Bishop, J. "Cardiac Output and Regional Blood Flow," Oxford, 1962.

5. Gebel', G. Ya. "Some Questions of Clinical Pathophysiology of Mitral Defects," author abstract of doctoral dissertation, Moscow, 1968.

6. Volynskiy, Yu. D. "Changes in Intracardiac Hemodynamics in the Presence of Heart Disease," Leningrad, 1969.

7. Bevegard, S., et al. ACTA PHYSIOL. SCAND., Vol 57, 1963, pp 26-50.

8. Formanek, G., et al. CIRCULATION, Vol 41, 1970, pp 833-841.

9. Green, G., et al. Ibid, Vol 45, 1972, pp 552-557.

10. Kloster, F., et al. AM. HEART J., Vol 79, 1970, pp 175-181.

11. Hyatt, K., et al. AEROSPACE MED., Vol 40, 1969, pp 644-650.

12. Bjurstedt, H., et al. ACTA PHYSIOL. SCAND., Vol 90, 1974, pp 491-500.

13. Idem, Ibid, Vol 96, 1976, pp 526-531.

14. Chobanian, A., et al. CIRCULATION, Vol 49, 1974, pp 551-559.

15. Arborelius, M., et al. AEROSPACE MED., Vol 43, 1972, pp 592-598.

16. Paley, H., et al. J. CLIN. INVEST., Vol 50, 1971, pp 2283-2294.

17. Saltin, B., et al. CIRCULATION, Vol 38, No 5, Suppl 7, 1968, p 7.

18. Aheborg, G., et al. SCAND. J. CLIN. LAB. INVEST., Vol 36, 1976, pp 193-201.

19. Pettyjohn, F., and McMeekin AVIAT. SPACE ENVIRON. MED., Vol 46, 1975, pp 1299-1304.

20. Thomas, M., and Longo, M. Ibid, Vol 47, 1976, pp 192-198.

21. Thompson, A., et al. Ibid, Vol 46, 1975, pp 69-73.

22. Meyerson, F. Z. "Adaptation to the Heart to Large Loads, and Cardiac Insufficiency," Moscow, 1975.

UDC: 612.014.462.6+612.015.1]-06:612.766.2

PARAMETERS OF ACID-BASE EQUILIBRIUM AND ENZYMATIC ACTIVITY OF BLOOD IN MAN DURING BRIEF ANTIORTHOSTATIC HYPOKINESIA

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian No 5, 1977 pp 51-58

[Article by V. Ye. Katkov, N. I. Kauricheva, V. V. Chestukhin, O. Kh. Zybin, R. D. Seyfulla and V. N. Utkin, submitted 25 Apr 77]

[Text] It is known that gravitational redistribution of blood combined with immobilization is associated with changes in metabolic activity of tissues [1-4]. This is reflected in the dynamics of parameters of acid-base equilibrium and enzyme activity in peripheral venous blood. For example, it has been demonstrated that a change in the direction of respiratory or metabolic acidosis and increased aspartate aminotransferase activity are observed during strict bed rest [2]. However, we still do not know in which organs and tissues of a healthy individual these changes are the most marked.

The objective of this investigation was to study the effect of brief antiorthostatic hypokinesia (AOH) on parameters of acid-base equilibrium and aminotransferase and alkaline phosphatase activity in blood flowing from various organs of a healthy individual.

Methods

We performed selective catheterization, taking blood samples from different parts of the cardiovascular system, before and after 5 days of bed rest in antiorthostatic position, with 4.5° tilt of the body, on healthy male volunteers. Catheterization was performed simultaneously with two catheters: a venous one (Cournand No 7), which was inserted into the punctured ulnar vein under roentgenological monitoring and passed into the vessels of different organs, and a soft arterial catheter that was kept in the radial artery at all times. Figure 1 illustrates the typical position of the venous catheter in several regions.

We recorded the gas composition of blood; the blood samples were calibrated with carbon dioxide in concentrations of 4.8 and 8.2%, followed by calculations on a Siggaard-Andersen nomogram at 37°C temperature [5]. Aspartate and alanine aminotransferases were assayed by the method of Reitman and Frankel', and alkaline phosphatase, by the method of Bodan'skiy [6].

61a)

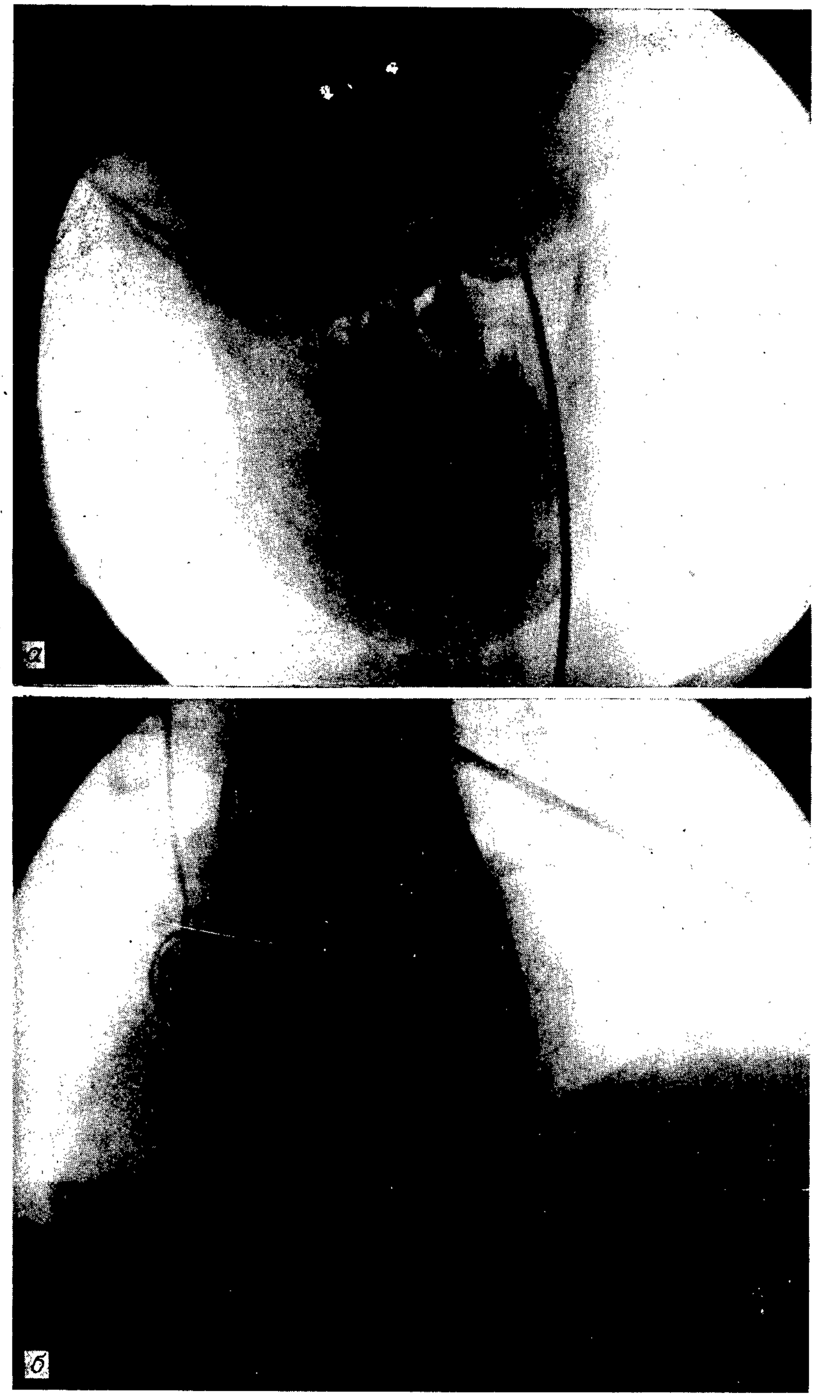


Figure 1. Typical position of catheters to take blood flowing from the brain (from superior bulb of internal jugular vein) (a) and mixed venous blood (from pulmonary artery) (b)

Results and Discussion

A decrease in standard bicarbonate, excess of bases and buffer bases, as well as some drop of pH were noted in blood from organic veins and, accordingly in mixed venous blood after AOH (Table 1). These changes were the most marked in blood flowing from the brain and least marked in blood from the kidney. It should be noted that a statistically reliable ($P<0.05$) decrease in buffer capacity was present only in blood flowing from the brain; only a tendency toward such decrease was demonstrated in blood flowing from other organs, as well as in mixed blood (Figure 2). These changes were rather vivid in blood flowing from the heart; however, the small number of cases did not enable us to pursue a statistical analysis thereof.

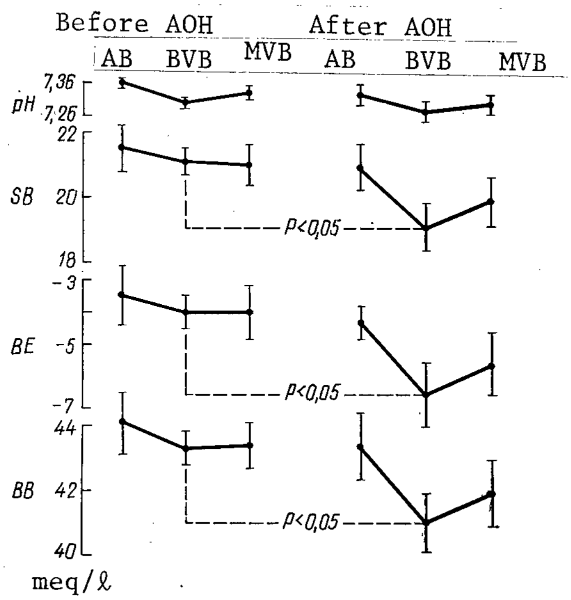


Figure 2.
Effect of AOH on pH and buffer capacity of arterial blood (AB), venous blood flowing from the brain (BVB) and mixed venous blood (MVB)

The tendency toward decrease of pH and buffer capacity was less marked in arterial blood than mixed venous blood; in addition, it showed some decline of PO_2 and elevation of PCO_2 (see Table 1).

Aminotransferases of arterial and mixed venous blood showed a tendency toward increasing, while alkaline phosphatase demonstrated some decrease (Table 2). The increase in activity of aspartate aminotransferase was somewhat more marked than that of alanine aminotransferase; and the increase in activity of the former was statistically reliable ($P<0.05$) only in blood flowing from the brain, liver and kidneys (Figure 3, B, D and E).

Thus, the obtained results indicate that there is a decrease in buffer capacity and increase in activity of aspartate aminotransferase in blood flowing from the brain following AOH; increased activity of the latter was also demonstrated in blood flowing from the liver and kidneys. In other words, the brain was found to be the most susceptible organ with regard to effect of simulated weightlessness, since it is only in blood flowing from the brain that there was statistically reliable change in the direction of metabolic acidosis, combined with increased enzyme activity.

Table 1. Effect of AOH (bottom line of numbers) on indices of acid-base equilibrium in blood samples taken from different parts of the cardiovascular system (M±m)

Blood	pH	PCO_2	SB	BE	BB	PO_2	n
Arterial	7,353±0,01	38,8±0,9	21,5±0,7	—3,5±0,9	44,1±0,9	97,5±5,0	12
	7,320±0,03	41,0±2,0	20,9±0,7	—4,3±0,5	43,4±1,0	90,3±4,5	7
Flowing from different organs:							
brain	7,304±0,01	45,9±1,6	21,1±0,7	—4,0±0,5	43,3±0,5	41,3±1,2	12
	7,279±0,03	45,0±3,0	19,1±0,7*	—6,4±1,0*	41,2±0,9*	41,2±1,8	7
heart	7,305±0,01	45,3±1,0	21,3±0,7	—3,4±0,9	44,3±0,9	25,0±0,7	4
	7,260±0,02	46,5±2,5	18,5±0,5	—7,3±0,8	40,5±1,0	25,5±0,5	2
liver	7,331±0,01	42,8±1,2	21,4±0,5	—3,5±0,6	44,1±0,5	46,9±1,2	12
	7,300±0,03	44,5±2,0	19,9±1,0	—5,6±1,1	42,0±1,2	46,7±2,5	7
kidney	7,339±0,01	42,0±1,3	21,7±0,7	—3,4±0,7	44,1±0,7	66,2±2,6	12
	7,306±0,03	42,9±3,2	20,2±0,9	—5,2±1,0	42,4±0,9	66,8±1,7	7
muscles of lower extremities	7,337±0,01	42,7±2,2	21,2±0,6	—3,9±0,7	43,7±0,8	45,3±1,5	12
	7,296±0,03	43,9±3,0	19,8±0,7	—5,9±0,9	41,6±0,8	48,3±3,1	7
mixed venous	7,332±0,02	42,7±1,4	21,1±0,6	—4,04±0,8	43,4±0,7	47,6±1,4	12
	7,294±0,03	44,5±3,0	19,9±0,7	—5,7±0,9	42,0±1,0	47,5±2,4	7

* $P<0,05$.

Key: PCO_2) carbon dioxide tension (mm Hg)
SB) standard bicarbonate (meq/ℓ)
BE) base excess (meq/ℓ)
BB) buffer bases (meq/ℓ)
PO_2) oxygen tension (mm Hg

Table 2. Effect of AOH (bottom line of numbers) on enzymatic activity in blood samples taken from different parts of the cardiovascular system (M±m)

Blood	AST	ALT	AP	n
Arterial	17,8±1,5	21,4±2,7	15,5±1,1	9
	24,3±3,3	25,5±3,0	14,8±2,6	6
Flowing from:				
brain	17,0±1,6	21,8±2,9	14,6±1,3	9
	26,9±3,3*	24,3±2,5	14,0±2,0	7
heart	17,3±2,9	18,0±2,0	16,0±2,2	4
	16,0±4,0	19,0±2,1	10,0±0	2
liver	18,0±1,2	19,8±2,5	15,0±1,2	9
	29,7±5,8*	29,1±5,1	15,4±1,9	7
kidney	16,2±1,2	20,2±2,5	17,7±1,2	9
	28,0±5,7*	24,3±3,1	15,4±1,7	7
muscles of lower limbs	17,5±3,4	20,8±2,4	18,2±1,6	9
	23,6±4,2	22,3±2,1	14,6±2,1	7
mixed venous	16,9±1,5	20,8±2,4	15,2±1,7	9
	24,3±4,0	23,1±2,8	14,6±1,7	7

* $P<0,05$.

Key:
AST) aspartate aminotransferase (in IU--international units)
ALT) alanine aminotransferase (IU)
AP) alkaline phosphatase (protein units)

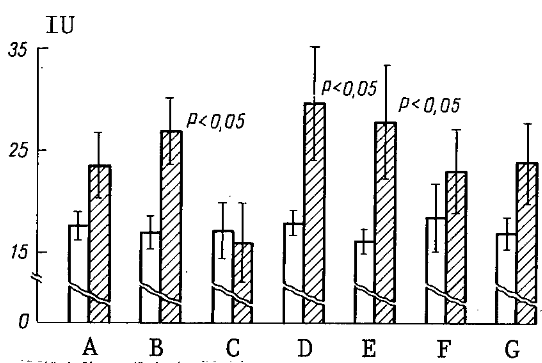


Figure 3.
Effect of AOH (shaded columns) on aspartate aminotransferase activity in blood samples taken from different parts of the cardiovascular system

At first glance, this conclusion appears paradoxical, since it is a known fact that the tissue of the brain, intercellular and spinal fluid are rather well-protected from metabolic changes (including very significant ones) in acid-base equilibrium in extracerebral regions and, accordingly, arterial blood [7-10]. For example, the study of Feuel et al. [7] on healthy volunteers, who underwent catheterization of an artery, internal jugular vein and puncture of the spinal canal, revealed that although administration

of NH_4Cl for 5 days did elicit qualitatively the same changes in acid-base equilibrium in both blood and spinal fluid, the latter presented about a 10-fold reduction of pH with 50% less bicarbonates than arterial blood, and these changes occurred against the background of marked hyperventilation.

It is easy to see that the changes due to AOH were opposite to those that the authors observed with a chronic "load" of H^+ ions. Indeed, in this study, the shift in the direction of metabolic acidosis in venous blood of the brain occurred in the presence of virtually unchanged acid-base equilibrium of arterial blood and in the absence of hyperventilation. In other words, AOH had a basically different effect on cerebral metabolism than a simple shift of acid-base equilibrium of arterial blood in the direction of metabolic acidosis. It may be assumed that this difference is due to the existence of new factors, i.e., immobilization combined with gravitational redistribution of body fluids in general and in the cranial cavity in particular.

Under these conditions, the reliable decrease in buffer capacity of blood flowing from the brain could be due either to increased permeability of the hematoencephalic barrier to bicarbonates, or resorption of more acid products of metabolism followed by their neutralization in blood. Of course, the location of these changes is far from indifferent to the functional state of brain tissue.

It is known that the buffer capacity of brain fluid and spinal fluid, as determined by the correlation between PCO_2 and HCO_3^-, is extremely negligible. The main reason for this is not so much the low bicarbonate content as the difference in permeability of the blood-fluid barrier to CO_2 and HCO_3^-, or more precisely, good permeability to CO_2 and virtually none to HCO_3^- [11-14]. However, even in spite of the negligible alkaline reserve, the pH of intercellular fluid of the brain is, as we have already mentioned, more constant than blood pH [7-10]. This could be due to increased permeability of the hematoencephalic barrier to bicarbonates, in the first place; triggering of mechanisms of their active transport, in the second place; increased electric potential between blood and intercellular fluid, which could be caused even by a negligible shift in pH of the latter, in the third place [8-10, 13, 15].

However, if these changes did occur during AOH, apparently they were not effective enough to compensate completely the metabolic changes. This is indicated by the clinicophysiological and experimental studies of a number of authors who observed, as we did, subjective (headache, sensation of blood rushing to the head, etc.) and objective (paroxysmal discharges on the EEG, changes in the rheoencephalogram, dystonia of cerebral vessels, etc.) signs that are typical of a change in the direction of metabolic acidosis [16-19], during this period of immobilization. Perhaps, expressly the acidosis was one of the causes of changes demonstrated on the 5th day of AOH in the vestibular, visual and gustatory analyzers.

We were also impressed by the fact that some extracerebral diseases, in particular acquired heart disease, may be associated with altered metabolic activity of the brain. This was confirmed once more by one of the authors

of this investigation who used an analogous technique to study metabolic activity and regional cerebral circulation in different groups of patients with acquired heart disease: mitral stenosis, combined mitral defect, stenosis of the aorta, combined aortal defect, combined defects, combined defects with insufficiency of aortal valves [20].

In the light of this investigation, the last group of patients with combined defects and insufficiency of aortal valves is of special interest, since they presented the same changes as after AOH: appreciable shift in the direction of metabolic acidosis in blood flowing from the brain, against the background of close to "normal" acid-base equilibrium of arterial blood. Evidently, this group of patients could be used for clinical modeling and deeper investigation of the effects of weightlessness on brain metabolism, as well as to test agents to prevent (treat) its deleterious effects on acid-base equilibrium and, perhaps, hemodynamics in this region.

Following AOH, increased aspartate aminotransferase activity was also observed in blood flowing from the brain, along with the shift in the direction of metabolic acidosis. It is rather difficult to determine how its activity changed in tissue proper, since the correlation between them depends on many factors: rate of change in enzyme activity in serum, rate of its release from tissue, share of enzyme subject to denaturation in situ, its distribution in intracellular tissue, etc.; however, in most cases, an increase in enzyme activity in blood coincides with a decrease in such activity in tissues [21-23]. If such a correlation was observed in our study, the decrease in tissular enzyme activity must have affected metabolism of amino acids, in particular glutamic acid. This, in turn, could lead to impairment of the process of detoxification of ammonia and formation of gamma-oxybutyric acid, which ultimately also affected acid-base equilibrium and the functional state of the brain.

There was also an increase in aspartate aminotransferase activity in blood flowing from the liver and kidneys; however, this apparently did not have as serious consequences to these organs as to brain tissue. It is known that the activity of this group of enzymes increases not only in the presence of pathological states, but is observed in healthy individuals, in some cases. Thus, selective catheterization of the hepatic vein of healthy volunteers revealed that a physical load leads to appreciable increase in transaminases in blood flowing from the liver [24]. In the authors' opinion, such changes could be due to relative hypoxia of hepatic tissue or increased membrane permeability to these enzymes, which is perhaps what occurred in our study.

Thus, the obtained results indicate that, after AOH, there was a shift in the direction of metabolic acidosis and an increase in activity of aspartate aminotransferase in blood flowing from the brain; there was also an increase in activity of this enzyme in blood flowing from parenchymatous organs, the liver and kidneys.

BIBLIOGRAPHY

1. Fedorov, I. V., et al. in "Aviakosmicheskaya meditsina. Tez. dokl. 5-y Vsesoyuz. konf." [Aerospace Medicine. Summaries of Papers Delivered at the 5th All-Union Conference], Moscow--Kaluga, Vol 2, 1975, pp 93-96.

2. Tigranyan, R. A., et al. Ibid, pp 187-190.

3. Chobanian, A., et al. CIRCULATION, Vol 49, 1974, pp 551-559.

4. Vernicos-Danellis, J. AVIAT. SPACE.ENVIRON. MED., Vol 47, 1976, pp 583-587.

5. Astrup, P. SCAND. J. CLIN. LAB. INVEST., Vol 8, 1956, pp 33-43.

6. Todorov, Y. "Clinical Laboratory Methods in Pediatrics," Sofia, 1968.

7. Feuel, V., et al. J. APPL. PHYSIOL., Vol 27, 1969, pp 67-76.

8. Mitchell, R., and Singer, M. Ibid, Vol 20, 1965, pp 905-911.

9. Mitchell, R., et al. Ibid, pp 443-452.

10. Ponten, U., and Siesjo, B. ACTA PHYSIOL. SCAND., Vol 71, 1967, pp 89-95.

11. Betz, E. PHYSIOL. REV., Vol 52, 1972, pp 595-631.

12. Siesjo, B., and Ponten, U. EXP. BRAIN RES., Vol 2, 1966, pp 176-190.

13. Skinhoy, E. ACTA NEUROL. SCAND., Vol 42, 1966, pp 604-607.

14. Berenyi, K., et al. CIRCULATION, Vol 52, 1975, pp 319-324.

15. Buchanan, N., and Eyberg, C. S. AFR. MED. J., Vol 48, 1974, pp 1471-1475.

16. Mikhaylova, O. M. ARKH. ANAT. [Archives of Anatomy], No 12, 1974, pp 59-61.

17. Yarulin, Kh. Kh., et al. KOSMICHESKAYA BIOL. [Space Biology], No 4, 1972, pp 33-39.

18. Astrup, P. SCAND. J. CLIN. LAB. INVEST., Vol 22, 1968, p 102.

19. Lassen, N., and Christinsen, M. BRIT. J. ANAESTH., Vol 48, 1976, pp 719-734.

20. Zybin, O. Kh. "Status of Some Parameters of Hemodynamics and Gas Exchange of the Brain of Patients With Acquired Heart Disease," candidatorial dissertation, Moscow, 1973.

21. Sobel, B., and Schell, J. in "Myocardial Infarction," Moscow, 1975, pp 58-75.

22. Jennings, F., et al. ARCH. PATH., Vol 64, 1957, p 10.

23. Wroblewski, F. PROGR. CARDIOVASC. DIS., Vol 6, 1963, p 63.

24. Foit, E., et al. PFLUG. ARCH. GES. PHYSIOL., Vol 361, 1976, pp 287-296.

UDC: 612.014.482:629.782:525

MAIN OBJECTIVES AND RESULTS OF THE RADIOBIOLOGICAL EXPERIMENT CONDUCTED ON THE KOSMOS-690 BIOSATELLITE

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian No 5, 1977 pp 58-66

[Article by Yu. G. Grigor'yev, Yu. P. Druzhinin, V. V. Verigo and Ye. A. Il'in, submitted 13 Dec 76]

[Text] Man and the living organisms that accompany him in space flights are exposed to a situation that is not encountered on earth. It is characterized primarily by weightlessness and the continuous effect of ionizing cosmic radiation. It is imperative to investigate the combined biological effect of ionizing cosmic radiation and weightlessness in order to solve the problem of assuring radiation safety of crews in the course of long-term space missions.

In order to study the concurrent effect of weightlessness and ionizing radiation, the biological objects must be exposed to radiation directly under space flight conditions. For this reason, Soviet and American scientists have concluded that one must use artificial sources of radiation onboard biosatellites in order to investigate the modifying effect of weightlessness on the radiobiological effect. This makes it possible to experiment with virtually any dosage of ionizing radiation in the presence of lengthy weightlessness, simulating in particular the possible exposure to radiation of spacecraft crews due to solar bursts. The Kosmos-690 biosatellite is one of these unique pieces of equipment.

Kosmos-690 was launched on 22 October 1974 into an orbit with the following parameters: maximum distance from earth's surface (in apogee), 389 km; minimum distance from earth's surface (perigee), 223 km; orbit inclination, 62.8°.

On 12 November 1974, i.e., after a 20.5-day flight, in accordance with the experimental program, the descent vehicle of the biosatellite made a landing. Figure 1 illustrates the program of the experiment on Kosmos-690.

The main objectives of radiobiological studies pursued on the biosatellite were as follows: 1) to obtain data on changes in radiosensitivity of animals

and distinctions of formation of radiation lesion under the combined effect of ionizing radiation and weightlessness during an actual space flight; 2) characteristics of biological effects of heavy ions of galactic cosmic radiation (GCR) on nervous tissue of mammals (rats) and other biological objects.

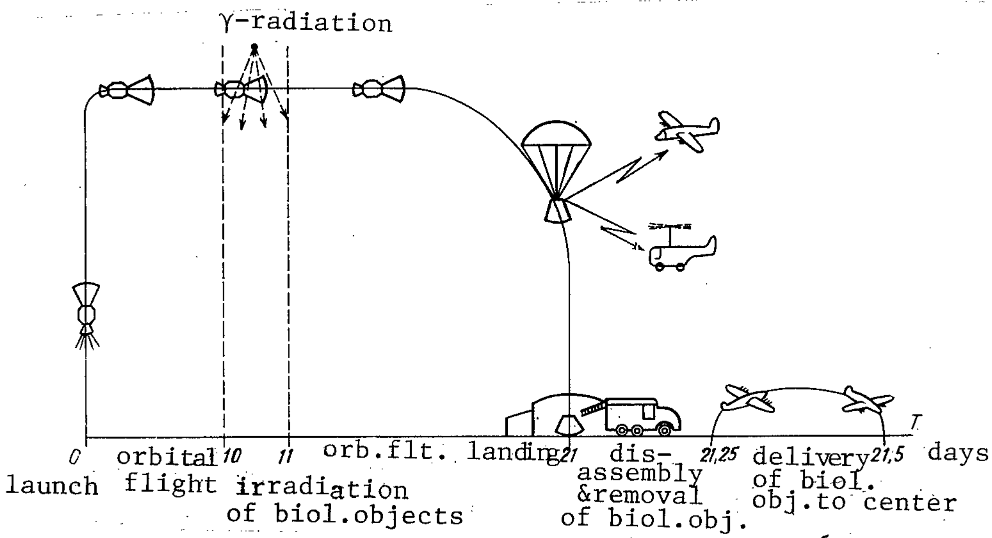


Figure 1. Diagram of radiobiological experiment on Kosmos-690 biosatellite

In the radiobiological experiments on Kosmos-690, the main biological objects were mammals: 35 Wistar rats that were kept in separate containers during flight, without being immobilized (Figure 2). There was a feeder, water dish and light in each container. The system of ventilation and collection of excreta made it possible to maintain optimum sanitary and hygienic conditions in the containers. A system of chemical regeneration of the atmosphere provided the animals with oxygen and removed carbon dioxide and other gas admixtures from the atmosphere. In the inhabited compartment, a temperature of 20 to 22°C was maintained and air pressure constituted 750-810 mm Hg; and oxygen pressure ranged from 150 to 210 mm Hg, depending on the mode of operation of the regeneration system, while relative humidity ranged from 60 to 70% (Figure 3). During the flight, motor activity was recorded by means of telemetry.

Before the flight, the rats underwent a thorough examination and special conditioning for the maintenance, feeding and water supply conditions. We selected the rats for the flight among 300 animals, with consideration of their weight, condition of peripheral blood, bactericidal properties of the skin and microflora of the fauces. We selected the most active and mobile rats, with maximum alimentary excitability, which demonstrated good orientation in their new habitat on the basis of a study of higher nervous activity by the maze method. Reactivity of the hemopoietic system, which

was determined by the epinephrine test, was an important criterion in selecting animals. This test was specially modified to apply to the experimental conditions aboard Kosmos-690.

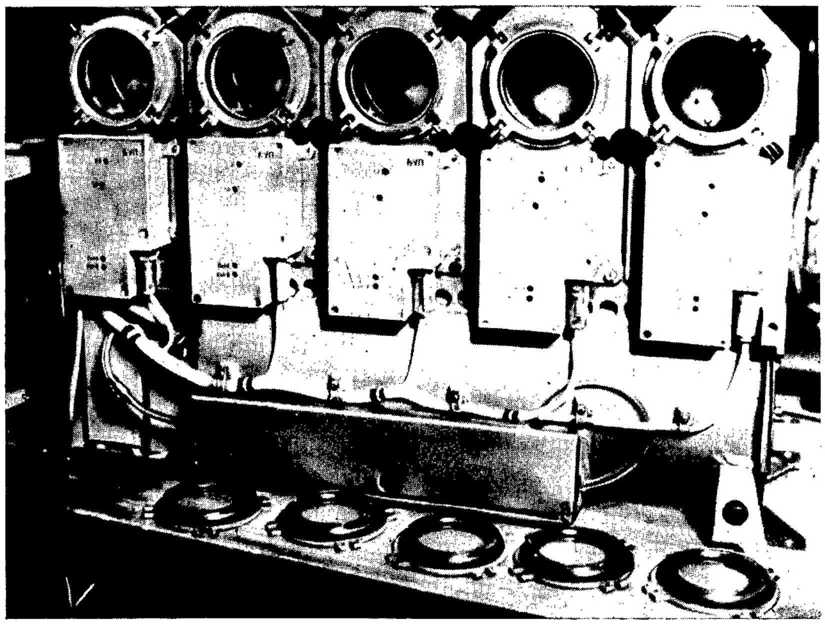


Figure 2. Rat-container unit

Onboard the biosatellite there was a ^{137}Cs gamma emitter with activity of 320 Ci. The onboard gamma emitter was developed on the basis of the prevailing radiation safety standards and with due consideration of the requirements of space technology. Much work was done to create a uniform field of irradiation. The use of a special filter made it possible to create a dose field with uniformity of ±10% and mean dose rate of 33.3 rad/h for one group of animals and 9.1 rad/h, for the other.

In accordance with the research program, the emitter was turned on by telemetry after 9 days of animal adaptation to the flight conditions. They were irradiated for 24 h, simulating the possible radiation conditions occurring with a powerful solar burst. Radiation was monitored by means of an onboard ionization dosimeter. In addition, the dosage delivered to each animal was established by means of individual thermoluminescent dosimetry. Processing of the obtained dosimetric data shows that the animals were irradiated in flight as stipulated in the program, and the mean absorbed doses constituted 220 rad (10 rats) and 800 rad (21 rats), 2 rats being exposed to 670 rad and 2 others, to 955 rad.

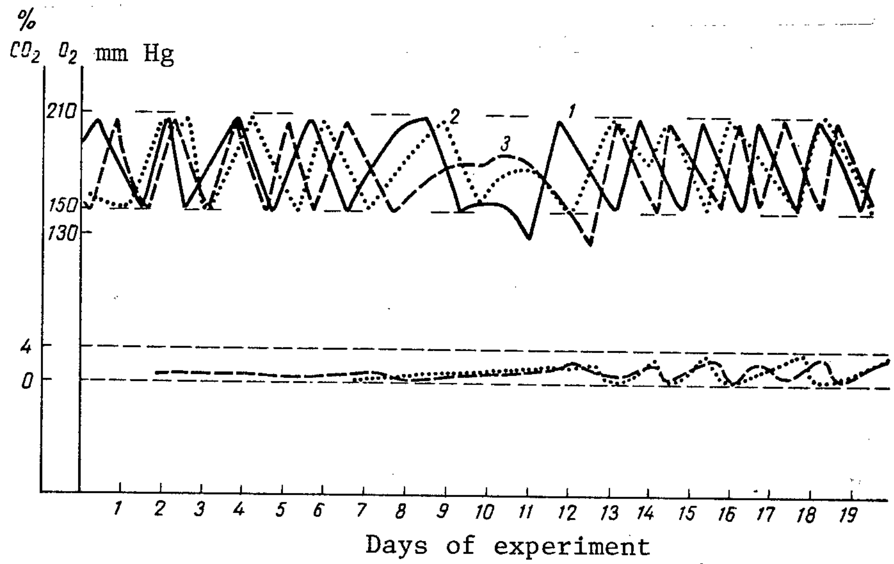


Figure 3. Microclimate features in flight and control experiments: oxygen content (A), carbon dioxide (B), humidity (C) and air temperature (D)

1) flight experiment
2) control-1 (preflight)
3) control-2 (postflight)

Control experiments were conducted on the ground, with simulation of all of the conditions on the biosatellite (with the exception of weightlessness) including radiation (control -1 and control-2). We also used several so-called vivarium (intact) controls and plotted the dose-effect curve under laboratory conditions. Control-1 differed from control-2 in that there was simulation of linear and impact G forces during the descent and landing.

The animals were submitted to a comprehensive examination 1-2 and 26-27 days after the biosatellite's descent vehicle landed, i.e., on the 11th-12th and 36th-37th postradiation days. We used modern physiological hematological, biochemical, morphological and other methods of examination.

Analysis of the data and comparison thereof were performed by means of mathematical methods. At the first processing stage, we used algorithms of applied statistics to evaluate the reliability of differences between compared groups. In those instances where we considered complex indices such as hemograms and myelograms, along with determination of Student's criterion for separate components, we also evaluated the differences between sets of indices using the multivariate criterion of Hotelling. For further processing of hematological data, we used methods of variance and factorial analysis, and mathematical models. Identification of the structural parameters of the model for different flight and control groups enabled us to make a quantitative evaluation of changes in functional status of the hemopoietic system under the influence of radiation and other space flight factors.

We placed dosimetry plates [film?] on the heads of some rats for topographic determination of passage of heavy ions of galactic cosmic radiation through the brain and identification of induced nerve cell lesions. In addition, we put special "units" onboard the biosatellite to evaluate the biological effect of GCR. These "units" contained, alternately with plate detectors, yeast and plant seeds.

Two rats exposed to 800 rad died within 2.5 days of the flight, and another rat exposed to the same dosage died on the 34th day after irradiation, presenting clinical signs of intestinal infection. Two rats died in control-1: 1 (exposed to a dosage of 955 rad) with marked signs of acute radiation sickness and the other (220 rad) due to concomitant pneumonia. In control-2, all of the animals survived. The death rate did not exceed 5% under laboratory conditions with a dosage of 800 rad. The difference in survival rate of flight and control rats is unreliable, although there was some tendency toward higher mortality in the flight group.

We analyzed the telemetry data characterizing general motor activity of the animals, food intake, as well as motor activity while eating ("alimentary motor activity") during the flight and in the control-1 and control-2 experiments. Exposure to 220 rad did not elicit a change in food intake by the animals, either on the biosatellite or in the control experiments. After exposure to a dosage of 800 rad radiation, there was a significant decrease in food intake by the animals on the 3d postradiation day (by 50-75%). Recovery of alimentary excitability to the initial level occurred on the 5th-7th postradiation day in control-1 and control-2. Recovery was slower in the flight experiment, and this parameter did not reach the base level on the 20th flight day.

The general condition of the animals was satisfactory immediately after the satellite landed. The rats were inactive and their muscle tone was diminished. There was a 50% decrease in soleus muscle contraction time after the flight (V. S. Oganov). The biochemical changes in muscles were more significant in the flight experiment (M. S. Gayevskaya).

By the end of the space flight, there was little difference in weight of rats exposed to 800 rad radiation, as compared to the base level (see Table). In these animals, at landing time weight gain was reliably lower than in control rats exposed to the same dose of radiation (Yu. I. Kondrat'yev). In the course of subsequent follow-up, the dynamics of changes in weight of animals exposed to 800 rad during the flight were different from the other rats: less intensive weight gain by the 25th postflight day (the experimental rats weighed 275 g and the controls, 310 g).

The experimental radiation conditions we selected lead to development in rats of the hemopoietic form of acute radiation sickness. The impaired reproductive capacity of bone marrow cells is related to the high radiosensitivity of stem cells. It is a known fact that radiosensitivity of stem cells constitutes about 100 rad. To study hemopoietic stem cells of rats, we used the method of exogenous clone formation with syngenic transplantation

of bone marrow cells to 4-5-week rats and xenogenic transplantation to F_1 generation of ($CBA \times C_{57}Bl/6$) mice. The former yielded the most objective information (A. Vatsek, G. N. Podluzhnaya). On the 12th postradiation day, with the use of a dosage of 800 rad, total CFU (colony-forming units) content of the rat femur was virtually the same (90.6 and 91.02) in weightlessness and the control-1 experiment, although it did not reach the level in the intact control (148.1). However, the difference in CFU content at the late stage is indicative of somewhat different kinetics of radiation lesion and postradiation recovery of this population of bone marrow cells. Similar results were also obtained by the method of xenogenic transplantation (V. N. Shvets). Morphological analysis of the colonies grown in the spleen of recipient rats revealed no appreciable disturbances, with regard to capacity for differentiation of hemopoietic stem cells in flight experiment animals. The capacity of stem cells to form colonies of erythroid and myeloid type cells remained unchanged (V. N. Shvets).

Weight of flight and control animals exposed to 220 and 800 rad radiation, on the 2d day after biosatellite landing and completion of experiments on the ground-based biosatellite model

Experiment	Radiation dose	Weight, g		
		before exp.	after exp.	change
Flight Control-1	800	223,5 219,2	239,8 263,9	16,4±3,43 44,7±5,0
Flight Control-1	220	223,4 223,4	256,2 274,9	32,8±4,65 51,9±3,2
Vivarium control		213,8	276,5	62,7±4,0

The hemopoietic system was submitted to comprehensive examination in the postflight period, and this permitted evaluation of repair regeneration of hemopoiesis (M. P. Kalandarova, G. P. Rodina). Exposure of animals to 800 rad radiation during the space flight was associated with somewhat more marked changes in hemopoiesis than irradiation on earth. This is indicated by the somewhat more marked change in number of leukocytes, lymphocytes and reticulocytes in blood, as well as myelokaryocytes, lymphocytes and reticular cells, monocytes and plasmacytes in bone marrow on the 12th-13th postradiation day (Figure 4). Thus, according to the number of myelokaryocytes, the radiobiological effect of irradiation during the flight, in a dosage of 800 rad, corresponded to the effect on earth of a dosage of 950 rad. Restoration of formed blood and bone marrow elements to normal levels by the 36th-37th postradiation day is indicative of the fact that regenerative processes were intact in the bone marrow of rats participating in the space flight, but apparently they were somewhat diminished. It is difficult to explain the somewhat more severe radiation lesion to hemopoietic organs during the space

flight with regard to some parameters, particularly since there was no change in the pool not only of stem cells but dividing hemopoietic cells, as compared to analogous ground-based controls in experiments with both the Kosmos-605 and Kosmos-690 biosatellites (G. P. Rodina). The osmotic stability of leukocytes was virtually the same in animals exposed to 220 rad in flight and in control-2 (35.4 and 30.3%, respectively) and did not differ from the vivarium control (26.2%). Exposure to 800 rad was associated with increased resistance of leukocytes, both in the flight and control (58.1 and 5.1%, respectively). No modifying effect of weightlessness on erythrocyte stability was demonstrated (L. V. Serova).

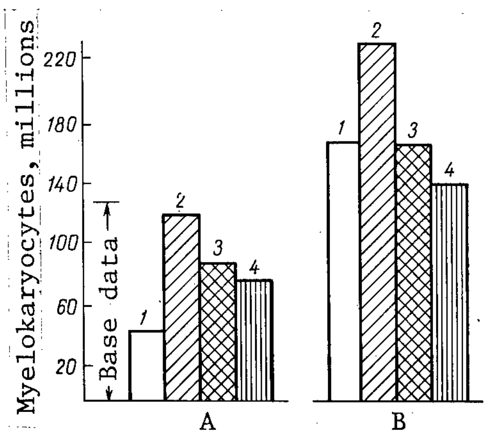


Figure 4.
Number of myelokaryocytes in rat bone marrow on the 11th-12th (A) and 36th-37th (B) postradiation day

1) flight (800 rad)
2) control-1 (800 rad)
3) control-2 (800 rad)
4) laboratory control (950 rad)

We examined the intensity of ultraviolet fluorescence (UVF) of peripheral blood lymphocytes in experimental and control animals (S. N. Aleksandrov, A. S. Yagunov, V. F. Safronov). As we know, UVF of cells is determined by the aromatic amino acids and proteins contained in them. The intensity of UVF increases linearly with increase in radiation dosage under the influence of irradiation of cells and tissues. It is minimally related to the dose rate and unrelated to delivery of radiation in divided doses (S. N. Aleksandrov). This criterion can be used to determine the magnitude of irreversible postradiation changes. In all, we examined 10 control and 20 flight animals (10 irradiated on earth and 10, in flight, in a dosage of 800 rad). The differences between series were unreliable.

Cytogenetic examination of bone marrow cells (T. P. Tsessarskaya) of rats exposed to 800 and 220 rad radiation failed to demonstrate reliable differences between the flight group and the group in the control-1 experiment; cells with aberrations constituted 3.4±0.89 and 2.39±0.79%.

Morphological studies of the hemopoietic system of rats exposed to 220 rad radiation failed to demonstrate an appreciable difference in dynamics of change in most formed elements of blood and bone marrow. Furthermore, there was even somewhat more active myelopoiesis in rats irradiated onboard the

biosatellite than in animals exposed to radiation on earth (control-1 and control-2). This is indicated by the somewhat higher level of leukocytes, neutrophils and juvenile forms of granulocytes, against the background of a normal level of myeloblast elements. However, these differences were unreliable.

The difference in effect of combined nonradiation environmental factors and radiation over a different range of doses is inherent in most ground-based experiments. The same difference was demonstrated in the experiment on Kosmos-690, according to the criterion of lesion to hemopoietic organs.

The epithelium of the gastrointestinal tract and spermatogenic epithelium are among the radiosensitive tissues. The combined effect of radiation and weightlessness led to a decrease in amount of lymphoid elements in the gastric mucosa, stroma of the villi of the small intestine and mucosa of the colon (V. V. Portugalov). The changes demonstrated in rats in the control-2 experiment were analogous in nature and severity to those seen in the flight group of animals.

Pathomorphological examination of the testes (organ weight, incidence of different elements of spermatogenic epithelium, histology of tubules) failed to demonstrate an influence of flight conditions on the radiation effect and course of repair processes (V. V. Portugalov). In addition, metaphase and anaphase methods were used to investigate chromosomal aberrations in the spermatogenic epithelium (M. D. Pomerantseva). There were no differences in incidence of chromosomal aberrations between rats exposed to a large dose of radiation in the flight experiment and those in the control-1 and control-2 experiments (22.6±5.5, 20.4±5.1 and 23.5±3.4% aberrant cells with the use of the metaphase method of analysis). With exposure to 220 rad radiation, there were more aberrations in animals irradiated during the flight (28.6±7.9%) than in the control-1 and control-2 experiments (9.9±1.0 and 9.9±3.6%); however, the differences are statistically unreliable. A study of the incidence of dominant lethal mutations in the spermatids, according to overall embryo mortality, preimplantation loss and postimplantation embryo mortality, revealed some increase in the radiation effect on the flight group exposed to 220 rad.

The corneal epithelium occupied an intermediate place between radiosensitive and radioresistant tissues. The yield of aberrant cells, visible in the mitotic anaphase, was found to be higher in the flight group (8.8±0.7) exposed to 800 rad radiation than in the analogous control-1 group (5.1±0.5%). At the same time, there was the same number of aberrant cells in the groups exposed to 220 rad radiation.

We were impressed by the fact that there was some accentuation of the biological effect of radiation during the space flight, with reference to radioresistant tissues: hepatic (diminished concentration and viscosity of DNA, increased triglyceride level, etc.) and muscle (decreased phospholipid content, etc.). On the 12th day after exposure to 220 rad radiation, DNA content of the rat liver showed a 30% decrease, and in control-2 a 19% decrease. After

exposure to a dosage of 800 rad, the DNA drop constituted 33 and 22%, respectively. There was appreciable normalization of this process in the experimental group, and the difference in restoration of DNA constituted 16-20%, as compared to the control series. In the spleen, like in the liver, DNA content was higher on the 12th postradiation day in the experimental group than in control-1 (25 and 11% with exposure to 220 rad, 32 and 29% with exposure to 800 rad respectively). Interestingly enough, this pattern did not prevail with respect to change in DNA content of bone marrow (F. T. Guseynov). Somewhat greater disturbances were observed in DNA structure of nuclear chromatin of the rat liver after irradiation during the flight (G. S. Komolova, V. F. Makeyeva).

Differences in corticosterone content of blood plasma were demonstrated in rats exposed to 220 rad radiation in space; its concentration increased, whereas in control animals it decreased (N. F. Kalita, R. A. Tigranyan).

An interesting finding was made from a study of protein fractions and their enzymatic activity in the myocardium of experimental and control rats (M. S. Gayevskaya). Irradiation of control animals led to a decrease in aspartate aminotransferase activity of sarcoplasmic proteins of the myocardium and increase in ATPase activity of myocardial myosin. Apparently, the effect of weightlessness predominated in the rats exposed to radiation in space (M. S. Gayevskaya), and this resulted in decreased activity of myocardial myosin ATPase.

Exposure to radiation in weightlessness elicited morphological and functional changes in coronary vessels of the heart and antigravity muscles, and retarded recovery processes in them during the period of readaptation to earth's gravity (V. V. Portugalov).

Factor analysis of several indices of the flight and control groups was performed to assess the relative importance of a number of factors (irradiation, G forces, the set of conditions involved in the space flight proper and overall effect of flight conditions and G forces during the descent and landing). The influence of flight conditions on number of myelokaryocytes in the femur was found to be reliable and more significant than the effect of differences in radiation dosage. G forces also had a strong effect on this parameter. Flight conditions also had a reliable effect on lymphocyte content of bone marrow. G forces had an insignificant effect on this index. Neither flight conditions nor G forces have an appreciable effect on peripheral blood parameters. Analysis of the weight of the thymus and spleen revealed that, while flight factors and radiation affect thymus weight equally, the changes in spleen weight were related primarily to flight conditions.

Thus, analysis of the results of the radiobiological experiment on animals aboard the Kosmos-690 biosatellite warrant the statement that the modifying effect of the set of nonradiation factors of space flight, including weightlessness, prevailing for 20.5 days, is not significant; the coefficient of the modifying effect, according to various indices referable mainly to

critical, radiosensitive organs, is close to 1.0 and does not exceed 1.2. This fact is consistent with our working hypothesis: evidently, the radiosensitivity of animals in the presence of physical environmental factors changes within the range of natural (daily, seasonal) variations in radiosensitivity, provided the physical agents do not exceed the limit of endurance of a given population. According to this hypothesis, the coefficient of modifying effect should not exceed 1.5 for acute radiation factors and 1.25 for long-term irradiation. The radiation on Kosmos-690 is referable to the latter type of radiation factor.

Definition of the magnitude of modifying effect of conditions prevailing in an actual space flight on the radiobiological effect is a step forward in evaluating the radiation hazard of space flights, as compared to previous studies involving simulation primarily of factors involved in the period of powered flight.

The research on the Kosmos-690 biosatellite was conducted by several scientific research institutes and organizations of the USSR, with the participation of specialists from CSSR and SRR [Socialist Republic of Romania], who collaborated within the framework of the Interkosmos program.

UDC: 612.744.1.015.1-06:612.766.2+
612.744.1.015.1-06:629.78

LACTATE DEHYDROGENASE ISOZYMES OF RAT SKELETAL MUSCLES FOLLOWING A SPACE FLIGHT AND WITH HYPOKINESIA

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian
No 5, 1977 pp 66-72

[Article by N. V. Petrova and V. V. Portugalov, submitted 11 Apr 75]

[Text] Research conducted in the last few years revealed that there is a great resemblance of disturbances that occur in the organism under the influence of weightlessness and hypokinesia. Limited mobility, like weightlessness, is associated with a diminished load on the skeletomuscular system and changes in hemodynamics. The lack or decrease in muscular activity leads to a number of interrelated disorders. Atrophic and dystrophic processes develop in muscles [1, 2, 3]. At the same time, there are no completely reliable data in the literature concerning the extent of similarity or difference between changes in metabolism of muscles in weightlessness and hypokinesia.

According to prevailing conceptions, in the case of limited mobility and in weightlessness, changes occur, first of all, in the "antigravity" muscles, i.e., extensors, which include the soleus and plantaris of the hind limbs. Model experiments conducted on the ground on animals revealed substantial morphological changes in these muscles in the case of hypokinesia [4]. To demonstrate the changes in metabolic processes, upon which the changes in structural organization of muscles are based, we used biochemical methods that make it possible to determine the direction of metabolism with exposure to experimental factors. We selected as our test object one of the key enzymes of carbohydrate metabolism, lactate dehydrogenase (LDH). LDH is represented in the organism in the form of five isozymes. There is a good correlation between the proportion of isozyme fractions of LDH and direction of tissular carbohydrate metabolism. Changes in tissular metabolism are reflected in the LDH spectrum [5].

Methods

A. Material

Studies were pursued of the soleus and plantaris msucles of four groups of male rats. The 1st group consisted of 14 rats that had returned from a

22-day orbital flight. Material for examination was taken from 8 rats on the 2d postflight day and from 6, on the 27th day after the flight. We used 15 rats from a ground-based model experiment, examined on the 2d (8 rats) and 27th (7 rats) day after termination of the experiment (2d group) to assess effects related to the animals' presence in a life-support system. The results of examining metabolism of the soleus and plantaris muscles of rats that had returned from the orbital flight were compared to the findings obtained from examination of the same muscles of 30 rats whose mobility was severely restricted--hypokinesia--for 7, 15, 36 and 60 days, during which they were kept in individual box cages (3d group). The general control (4th group) consisted of 50 rats kept in the vivarium. The control animals were examined at the same times as the experimental ones. We took samples of two muscles of the hopping group, the syleus and plantaris, which were frozen in dry ice and stored for several days at -70° until ready to be used.

B. Determination of isozyme composition of LDH

We prepared a tissue extract for analysis: a batch of tissue was ground in a glass homogenizer in 0.25 M saccharose and cell fragments were precipitated by centrifuging.

We examined the isozyme composition of LDH by the method of electrophoresis in polyacrylamide gel. We diluted skeletal muscle proteins by the method of Davis [6] with the minor modifications proposed by Dietz and Lubrano [7]. Since we had relatively small amounts of tissue at our disposal (10 to 30 mg), we used a microvariant of the technique, which enabled us to examine samples containing 1-3 μg protein. To increase the resolution of the method, electrophoresis was performed in 1.5×3×50 mm capillaries. The electrophoresis chamber enabled us to examine 12 samples at a time. Extract was applied to the gel, in amounts of 5-10 μℓ, using a microsyringe. We determined the volume and dilution of extract at the start of the experiment. Electrophoresis was performed at a voltage of 180-200 V and current of 8-10 mA per 12 capillaries for 60 min. We determined the specific activity of LDH fractions by the method involving the use of blue tetrazolium [7]. Quantitative assay of LDH isozymes was made by scanning flat gels in an IFO-451 recording microphotometer. We measured the areas of separate LDH fractions on a densitogram with a planimeter, and we calculated the size of each fraction as percentage of their sum.

The reliability of the obtained data was determined by the method of variance statistics using the nonparametric X criterion of Van der Varden [8], with bilateral limits and 5% critical level of importance. To obtain the values of criterion X, we arranged all of the existing variants of values of x (experiment) and y (control) in an ascending line; in this series, r is the sequential number of x and y_c; n is the number of random values of $x_i \ldots\ldots x_g$ and $y_i \ldots\ldots y_h$, $n = g+h$.

Criterion X is a function of $\psi \frac{r}{n+1}$;

$$X = \Sigma \psi \frac{r}{n+1}.$$

The obtained value of criterion X was evaluated from the table of "Limits of critical region for criterion X" [8]. If the obtained value was higher than the tabular value of X_p, the difference between groups of findings was deemed significant, with the appropriate level of probability P.

Results and Discussion

Normally, there is predominantly aerobic conversion of carbohydrates in the soleus, and it has a "cardiac" type of isozyme spectrum of LDH (Figure 1a).

Twenty-two days of weightlessness had an appreciable effect on the course of metabolic processes in the soleus of the rats. On the 2d postflight day, 4 out of the 5 fractions in the LDH isozyme spectrum presented a reliable increase in activity: activity of LDH_1 and LDH_2 diminished and that of LDH_4 and LDH_5 increased (Table 1). Such a spectrum could be classified as the "intermediate" type (Figure 1b). Morphological studies revealed that there was development of atrophic (decreased area of cross section) and dystrophic (waxy degeneration and necrosis) changes in muscle fibers of the soleus muscles we examined. Thus, the changes in LDH spectrum of the soleus muscle of rats after returning from the flight are indicative of the fact that development of atrophy and dystrophy of this muscle in flight is associated with increased glycolytic processes. Dietlein [9] called attention to the possibility of development of inflight muscular atrophy; he believed that considerably marked muscular atrophy begins after 14 days of flight if no preventive measures are instituted.

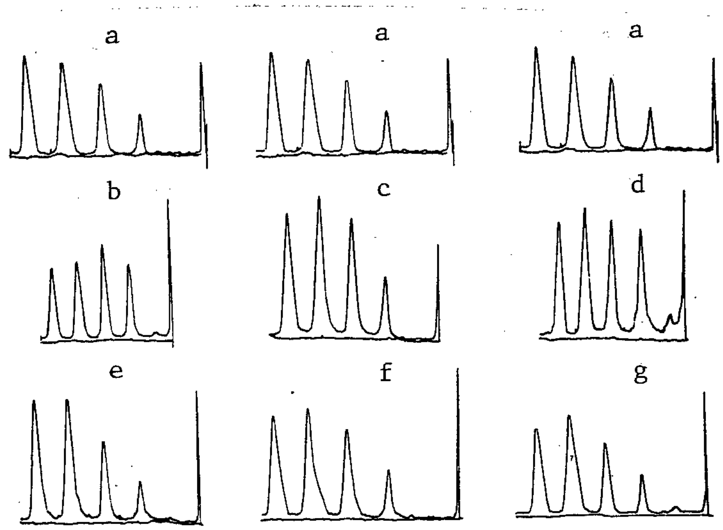


Figure 1. Isozyme spectrum of LDH. Soleus muscle.

a) control
b) 2d postflight day
c) 2d day after model experiment
d) 15th day of hypokinesia
e) 27th postflight day
f) 27th day after model experiment
g) 35th day of hypokinesia

Table 1. Quantitative correlation between isozyme fractions of LDH in the rat soleus muscle

Isozyme	Control	After space flight				After model experiment				Control	Hypokinesia							
		2d day (8)		27th day (6)		2d day (8)		27th day (5)			7th day (5)		15th day (8)		35th day (7)		69th day (9)	
		%	X	%	X	%	X	%	X		%	X	%	X	%	X	%	X
LDH1	29,1	22,2*	4,67	31,2	2,05	30,3	1,5	28,6	1,14	31,5	28,8	1,37	22,2*	5,66	26,2	4,5	27,4*	5,0
LDH2	34,6	25,9*	5,61	34,2	0,81	35,9	2,6	34,3	0,80	35,2	31,6	1,64	27,3*	5,21	37,6	2,34	39,7*	—5,44
LDH3	23,0	25,5	—2,5	20,1	2,65	22,6	1,84	23,9	—0,63	20,4	21,7	—0,62	25,8*	—4,07	22,1	2,75	21,2	—1,08
LDH4	10,0	20,1*	5,63	10,9	0,32	9,2	1,73	10,4	—0,04	8,8	13,6*	—3,31	18,3*	—5,5	9,1	0,74	7,6	1,57
LDH5	3,3	6,3*	3,89	3,6	0,68	2,0*	4,82	2,8	2,35	4,1	4,3	—0,61	6,4*	—4,48	5,0	—1,37	4,1	0,05
X_0			3,49		2,96		3,49		2,72			2,72		3,49		3,24		3,73

Note: Here and in Table 2: X and X_0 are arbitrary units calculated and tabular values with 5% significance level; asterisks refer to LDH fractions differing reliably from the control; the number of animals is indicated in parentheses.

Table 2. Quantitative correlation between isozyme fractions of LDH in the rat plantar muscle

Isozyme	Control	After space flight				After model experiment				Control	Hypokinesia					
		2d day (8)		27th day (6)		2d day (8)		27th day (7)			7th day (5)		35th (7)		60th (8)	
		%	X	%	X	%	X	%	X		%	X	%	X	%	X
LDH1	4,9	6,1*	4,49	3,5	1,65	5,7	3,3	4,1	0,79	9,6	7,7	1,85	7,8	2,69	11,5	3,14
LDH2	10,4	11,0	—1,34	7,3	1,92	8,4	2,9	8,4	2,20	15,2	12,2	2,12	13,3	1,38	19,5	3,27
LDH3	16,7	16,9	—0,89	12,8*	3,24	12,7*	4,21	13,3	2,72	18,4	18,2	0,11	16,5	2,69	20,7	2,1
LDH4	27,7	32,3	3,4	21,7*	4,08	23,1*	5,61	27,5	1,88	24,2	24,6	—0,60	26,1	—1,96	26,0	1,21
LDH5	40,3	33,7	2,79	54,7*	4,09	50,1*	4,73	45,7	—2,33	32,6	37,3	—1,35	36,3	2,26	22,3*	4,55
X_0			3,49		2,92		3,49		3,24			2,72		3,24		3,49

It is important to indicate that keeping the rats under the conditions of the ground-based experiment did not lead to appreciable changes in soleus metabolism; there was only a reliable decrease in activity of LDH_5, which was not associated with a change in the nature of the isozyme spectrum (Figure 1c).

The metabolic changes in the soleus were reversible. The correlation between LDH fractions of the soleus reverted to normal 27 days after the flight and model experiment (see Table 1; Figure 1, e and f).

The plantar (mixed) muscle is normally characterized by anaerobic metabolism. This is reflected in the isozyme spectrum of LDH. Normally, there is prevalence of M type fractions (LDH_4 and LDH_5); such a spectrum is called "muscular" (Figure 2a). On the 2d postflight day, the rats presented an insignificant increase in rapid (H type; reliable increase only in LDH_1 activity) and decrease in slow (M type) fractions of LDH; this was not associated with a change in the spectrum, and it remained "muscular" (Table 2; Figure 2b).

On the 27th postflight day, increased activity of LDH_5 was demonstrated in the plantar muscle, but the nature of the spectrum did not change (Figure 2e). At the same time, a normal correlation between LDH fractions was not yet restored: LDH_3 and LDH_4 activity remained reliably lower (see Table 2). Thus, postflight recovery processes did not proceed similarly in red and mixed muscles and did not terminate at the same time. Our findings are consistent with the data of T. Yu. Shchesno [10], to the effect that recovery processes are faster in red muscles than white.

On the 2d day after the model experiment, a reliable increase in LDH_5 activity was demonstrated in the plantar muscle, with reliable decrease in activity of LDH_3 and LDH_4, and retention of the general nature of the LDH spectrum (Figure 2c). On the 27th day after the model experiment, metabolism of the plantar muscle reverted to normal, as indicated by the correlation between activity of LDH fractions (see Table 2; Figure 2f).

Under hypokinetic conditions, there was substantial change in isozyme spectrum of LDH of the soleus. The changes were not the same at different stages of the experiment. On the 7th day of hypokinesia, when development of dystrophic processes had only begun, according to morphological findings [2], there was reliable change in only one LDH fraction (LDH_4), with a general shift of the spectrum in the direction of the "muscular" type. The most marked changes in isozyme composition occurred on the 15th day of hypokinesia. At this time, the activity of all five isozyme fractions differed reliably from normal. LDH_1 and LDH_2 activity diminished, while that of LDH_3, LDH_4 and LDH_5 increased (see Table 1; Figure 1e). The increase in slow fractions in the LDH spectrum was indicative of profound metabolic changes in the muscle: progression of glycolytic processes. According to the results of morphological studies [3], there were distinct processes of dystrophy and atrophy of muscle fibers on the 14th-15th day of hypokinesia. In the opinion of Kaplan and Cahn [11], there is a correlation between severity of dystrophy and LDH spectrum: the

greater the dystrophy, the more the LDH spectrum is of the "early embryonic" type (a spectrum in which there is prevalence of M type fractions) in the muscle. With continued hypokinesia, there was less manifestation of atrophy and dystrophy, the weight of the muscle began to increase, but remained lower than in the control. With increase in duration of hypokinesia, the soleus regained the "cardiac" type of LDH spectrum. On the 35th experimental day, the LDH spectrum of the soleus of experimental animals did not differ from the spectrum of controls (Figure 1g). On the 60th day of hypokinesia, the LDH spectrum of the soleus was of the "cardiac" type, but the correlation between its fractions did not revert to normal (reliable decrease in LDH_5 activity). The latter indicates that, in the case of prolonged hypokinesia, a new metabolic level is established in the muscle, which is close to normal but not the same.

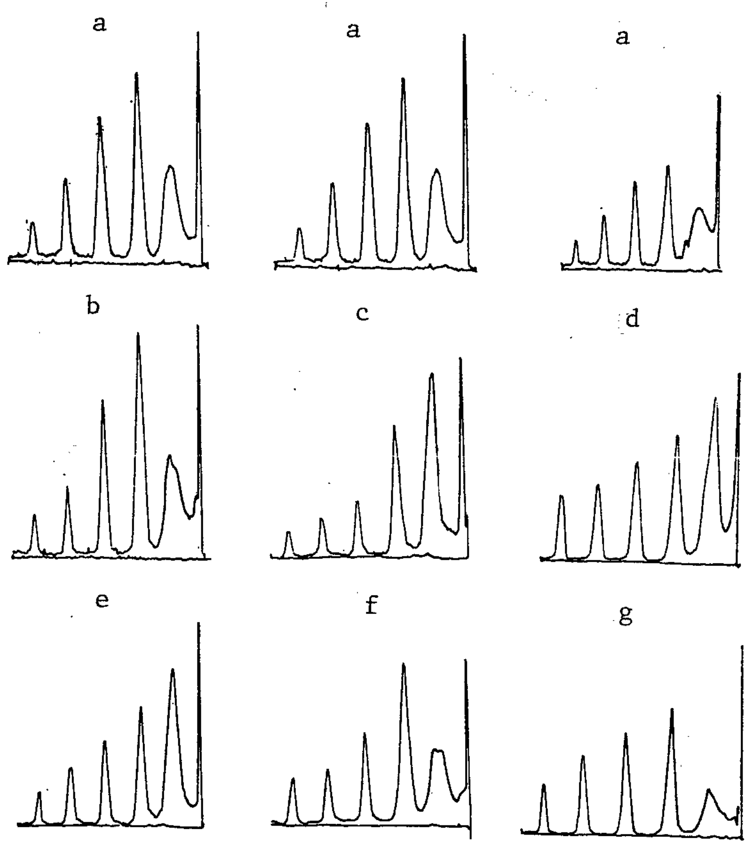


Figure 2. Isozyme spectrum of LDH. Plantar muscle

a) control
b) 2d postflight day
c) 2d day after model experiment
d) 35th day of hypokinesia
e) 27th postflight day
f) 27th day after model experiment
g) 60th day of hypokinesia

The change in correlation between LDH fractions of the soleus of rats after the flight is very similar to the change in LDH spectrum in the same muscle after 15 days of hypokinesia. This is indicative of the similarity of nature of changes in muscle metabolism arising in weightlessness and with limitation of motor activity.

In the case of hypokinesia, atrophy of the plantar muscle developed more slowly. Evidently, this is related to its distinctive chemical organization, blood supply and innervation. Normally, conversion of carbohydrates in the plantar (mixed) muscle occurs through anaerobic breakdown in glycolytic reactions, and there is prevalence of M type fractions in the LDH spectrum [12]. Studies revealed that it is only on the 60th day of hypokinesia that the isozyme composition of the plantar muscle differed reliably from the control in that activity of the LDH_5 fraction was diminished; but the nature of the spectrum remained "muscular" (see Table 2; Figure 2g). The different correlation between isozyme fractions indicates that, under these conditions, there is a slight increase in respiratory activity, with prevalence of glycolytic processes. At other stages of hypokinesis (7th-35th days), we failed to demonstrate a reliable change in activity of isozyme fractions, as compared to the control (Figure 2d).

The nature of the LDH spectrum of the plantar muscles of rats in the case of hypokinesia and weightlessness is indicative of similarity of metabolic changes in mixed muscles under these conditions.

To sum up the foregoing, we deem it possible to state that our study confirmed, once more, the validity of choosing hypokinesia as a model that permits reproduction of some of the effects of weightlessness on earth. There are also grounds to maintain that disturbances referable to carbohydrate metabolism play a leading role in development of atrophic and dystrophic changes in skeletal muscles in the presence of a diminished functional load on the skeletomuscular system and that one can assess the severity of changes in muscles according to the nature of changes in isozyme spectrum of LDH.

BIBLIOGRAPHY

1. Barbashova, Z. I.; Zhukov, Ye. K.; Baklanova, S. M.; et al. in "Adaptatsiya k myshechnoy deyatel'nosti i gipokinezii" [Adaptation to Muscular Activity and Hypokinesia], Novosibirsk, 1970, pp 26-35.

2. Bukayeva, I. A. "Cytological and Cytochemical Characteristics of Hypokinetic Skeletal Muscles," author abstract of candidatorial dissertation, Moscow, 1970.

3. Portugalov, V. V.; Il'ina-Kakuyeva, Ye. I.; Starostin, V. I.; et al. ARKH. ANAT. [Archives of Anatomy], No 11, 1971, pp 82-91.

4. Portugalov, V. V., and Il'ina-Kakuyeva, Ye. I. AEROSPACE MED., Vol 44, 1973, pp 764-768.

5. Kaplan, N. O. BACT. REV., Vol 27, 1963, pp 155-169.

6. Davis, B. J. ANN. N.Y. ACAD. SCI., Vol 121, 1964, pp 404-427.

7. Dietz, A. A., and Lubrano, T. ANALYT. BIOCHEM., Vol 20, 1967, pp 246-257.

8. Van der Varden, B. L. "Mathematical Statistics," Moscow, 1960.

9. Dietlein, L. F. ELECTRON. NEWS, Vol 9, 1964, pp 4-11.

10. Shesno, T. Yu. in "Tezisy dokladov Vsesoyuznoy konferentsii po myshechnoy biokhimii" [Summaries of Papers Delivered at the All-Union Conference on Muscle Biochemistry], Moscow--Leningrad, 1966, pp 151-152.

11. Kaplan, N. O., and Cahn, R. D. PROC. NAT. ACAD. SCI. (Washington), Vol 48, 1962, pp 2123-2130.

12. Dawson, D. M.; Goodfriend, T. L.; and Kaplan, N. O. SCIENCE, Vol 143, 1964, pp 929-933.

UDC: 629.78:[612.432+612.826.4].018

MORPHOLOGICAL MANIFESTATIONS OF FUNCTIONAL CHANGES IN THE HYPOTHALAMO-HYPOPHYSEAL NEUROSECRETORY SYSTEM AND RAT KIDNEYS UNDER THE INFLUENCE OF SPACE FLIGHT FACTORS

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian No 5, 1977 pp 72-76

[Article by Ye. A. Savina, A. S. Pankova and Ye. I. Alekseyev, submitted 1 Oct 75]

[Text] Cosmonauts have presented changes in hormone balance and fluid-electrolyte metabolism during space flights and upon returning to earth. In particular, with the return to earth's gravity, diminished diuresis, decreased excretion of electrolytes and increased antidiuretic activity have been observed [1, 2]. It is interesting to investigate the hypothalamo-hypophyseal neurosecretory system (HHNS) and kidneys of rats that had spent 22 days in flight on the Kosmos-605 biosatellite.

Methods

The supraoptical nuclei of the hypothalamus, posterior lobe of the hypophysis and kidneys were submitted to morphological examination 48 h and 27 days after the space flight. We examined the hypothalamus of 11 animals, the posterior lobe of the pituitary and kidneys of 15 rats. Animals in a model ground-based experiment and rats maintained in the vivarium, which were sacrificed at the same times as the experimental animals, served as a control.

The hypothalamus and pituitary were fixed in a mixture of mercuric chloride and formalin (9:1) and imbedded in paraffin. We demonstrated neurosecretory granules in neurocytes of the hypothalamic supraoptical nuclei using basic brown and light green according to V. K. Podymov [3] and paraldehyde fuchsin according to Gomori; ribonucleoproteins were demonstrated according to Einarson. An RA-4 drafting machine was used for karyometry of neurocytes. With a linear magnification of 2000×, the outline projections of 100 nuclei of hypothalamic cells from each animal were drawn. We then measured the long (L) and short (D) diameters of cell nuclei and determined the logarithms of their volumes using the formula of ellipsoid rotation, $V = \frac{\pi}{6}(LD)^{3/2}$ and nomograms of Fischer and Inke [4]. Subsequent estimates were made using the usual karyometric methods of variance statistics and the logarithmic method of separating empirical data into classes [5].

The rat kidneys were fixed in Zenker-formol and imbedded in paraffin. Morphological evaluation of the condition of the juxtaglomeral system (JGS) was made by means of determining granularity of JGS cells stained according to Bowie, with calculation of the juxtaglomerula index (JGI).

Results and Discussion

On preparations stained with hematoxylin-eosin, plethora of small vessels and capillaries, enlargement of neurocytes, dilatation of the perinuclear eosinophilic zone and constriction of bands of basophilic substance in peripheral regions of the cytoplasm were demonstrated in supraoptical hypothalamic nuclei 2 days after the flight. So-called nucleoloid bodies were observed in the eosinophilic zone of the cytoplasm of many neurocytes, and 2-3 such bodies were demonstrable in some cells. Demonstration of neurosecretory substance revealed that, in most cells, the granules are uniformly distributed throughout the cytoplasm, unlike control animals, in which they form accumulations mainly around the nuclei (Figure 1). There was a visible decrease in neurosecretion content of axons on the nuclear level. Concurrently with the change in distribution of neurosecretory granules in neurocytes, there is a decrease in intensity of ribonucleoprotein staining in peripheral regions of the cytoplasm. Determination of the volume of the nuclei enabled us to demonstrate a statistically reliable enlargement, as compared to animals in the ground-based experiment and vivarium control (see Table). In most nuclei, the nucleoli were large, eccentrically arranged and binucleolar cells were encountered more often than in control animals. Marked plethora was seen in the posterior lobe of the hypophysis. We could differentiate between experimental and control animals with certainty according to extent of plethora. The neurosecretion content of the posterior lobe of the pituitary was appreciably decreased, mainly due to a decrease in number, size and optical density of collecting neurosecretory bodies. Such changes in HHNS were not demonstrated in the animals of the model ground-based experiment.

Volume of nuclei of secretory neurocytes of rat hypothalamic supraoptical nuclei

Animal group	Number of animals	Volume of neurocyte nuclei, μm^3
Flight group (2d postflight day)	5	548.6±30.9*
Ground-based model experiment (2d day after termination of experiment)	5	396.2±19.9
Vivarium control	10	392.0±15.6

*P<0.001

Examination of the kidneys revealed a statistically reliable increase in their weight; however, we were unable to determine the cause of this phenomenon, since we failed to detect either circulatory disorders or changes in structural components of nephrons and interstitial tissue. Special mention must be made of the condition of the JGS, the cells of which produce renin.

Granular cells were demonstrable in afferent arterioles of the glomerules situated in the superficial and central parts of the cortex in animals sacrificed on the 2d postflight day. There were more cells containing granules, but most cells corresponded to 1st-2d grade granulation according to amount of granules. JG cells containing many granules were rarely seen; In the flight group of animals, the JGI was considerably lower (16.8±0.1) than in the vivarium control (23.7±0.3) and animals in the model ground-based experiment (24.7±0.18).

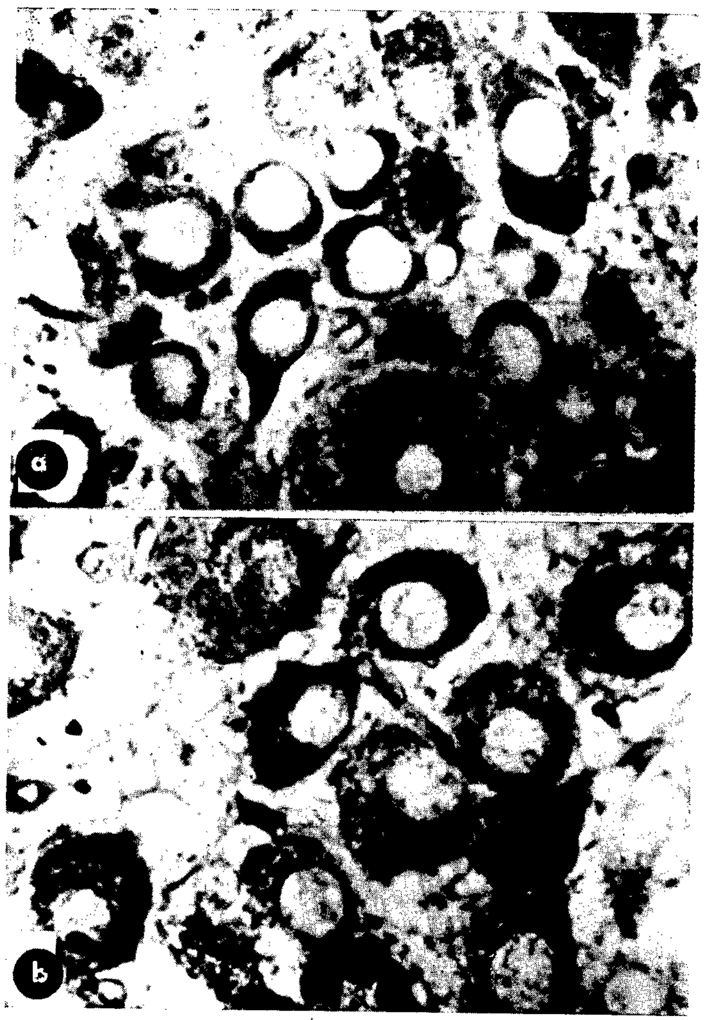


Figure 1. Supraoptical nucleus of the hypothalamus. Paraldehyde fuchsin stain according to Gomor; ocular 10×, obj. 60×

a) control; predominantly perinuclear localization of neurosecretion granules in neurocyte cytoplasm
b) 2d postflight day; enlargement of neurocytes; diffuse distribution of neurosecretion granules in cytoplasm.

In rats sacrificed 27 days after the flight, HHNS presented normalization of histochemical properties of neurocytes and size of their nuclei. No morphological signs of JGS activation were demonstrable in the kidneys (Figure 2). In particular, the numerical value of JGI of the flight group of rats (26.1±0.15) did not differ reliably from animals in the ground-based model experiment (27.1±0.1).

Figure 2.
Kidney. Bowie staining; ocular 10×, objective 90×

a) 27th postflight day
b) 27th day after ground-based experiment

Granularity of JG cells in the wall of the afferent artery of the glomerules is the same in both groups of animals

Analysis of the obtained data revealed that there is an increase in volume of nuclei and size of neurocytes, decreased intensity of staining of their basophilic substance, relatively uniform distribution of neurosecretion granules in cytoplasm with an increase in content thereof in axons, both on the level of the hypothalamic nuclei and terminal axons of the posterior lobe of the hypophysis on the first 2 days after the flight. The above set of changes is observed, as we know, when there as an increase in functional activity of HHNS with exposure to diverse extreme factors [6-8], and it may be indicative of increased secretion of antidiuretic hormone (ADH). Nevertheless, no morphological signs of antidiuresis due to the effect of ADH were demonstrable in the kidneys. At the same time, the kidneys of rats in the flight group presented signs of increased JGS activity, which were not demonstrable in rats in the ground-based model experiment. The lack of changes in HHNS and JGS of kidneys of rats in the ground-based model experiment

warrants the belief that they are due to factors prevailing during the flight and in the readaptation period. The changes demonstrated in animals on the 2d postflight day were similar to those we observed in our study of the morphological manifestations of HHNS reactions during 24-h exposure to low accelerations [9, 10], which led to an increase in functional activity of hypothalamic neurocytes and renal JGS. We also demonstrated a significant drop of JGI in rats exposed to longitudinal acceleration of 4 G for 16 and 24 h, and we evaluated degranulation of JG cells as an increase in activity of the renin-angiotensin system [11].

On the basis of comparison of the data obtained from this study to the results of 24-h exposure to accelerations, it may be assumed that the changes found on the 2d postflight day are induced by readaptation of the animals to earth's gravity. This is also consistent with the data indicative of increased antidiuretic activity of blood and angiotensin in cosmonauts on the 1st day after returning to earth.

Thus, animals sacrificed on the 2d postflight day demonstrated signs of increased activity of HHNS and JGS of the kidneys, which are apparently indicative of a compensatory reaction to maintain fluid-electrolyte equilibrium. However, studies must be pursued within the first hours after animals return to earth to make a definitive assessment of the functional state of these systems under space flight conditions.

BIBLIOGRAPHY

1. Balakhovskiy, I. S., and Natochin, Yu. V. "Metabolism Under Experimental Space Flight Conditions and Simulation Thereof," Moscow, 1973, pp 89-167.

2. Berry, Ch. A. in "Man in Space," Moscow, 1974, pp 51-70.

3. Podymov, V. K. SUD.-MED. EKSPERT. [Forensic Medical Expertise], No 1, 1964, pp 12-15.

4. Fischer, J., and Inke, G. ACTA MORPHOL. ACAD. SCI. HUNG., Vol 7, 1956. pp 141-165.

5. Khesin, Ya. Ye. Nuclear Size and Functional State of Cells," Moscow, 1967, pp 10-33.

6. Andrianova, L. A. in "Problemy kosmicheskoy meditsiny" [Problems of Space Medicine], Moscow, 1966, pp 29-30.

7. Vladimirov, S. V. "The Hypothalamohypophyseal Neurosecretory System of Some Mammalian Species Under Normal Conditions and as Affected by Dehydration or Nociceptive Stimuli," author abstract of candidatorial dissertation, Moscow, 1963.

8. Polenov, A. L. in "Gipotalamicheskaya neyrosecretsiya" [Hypothalamic Neurosecretion], Leningrad, 1971, pp 97-121.

9. Podymov, V. K. KOSMICHESKAYA BIOL. [Space Biology], No 6, 1970, pp 18-23.

10. Savina, Ye. A.; Pankova, A. S.; and Podymov, V. K. Ibid, No 3, pp 21-26.

11. Pankova, A. S., and Savina, Ye. A. Ibid, No 6, 1972, pp 19-23.

UDC: 612.886-087.5:613.693

EFFECT OF HEAD ORIENTATION IN THE GRAVITY FIELD ON SEVERITY OF CALORIC NYSTAGMUS

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian No 5, 1977 pp 76-80

[Article by V. N. Krut'ko, B. I. Polyakov and M. I. Serebrennikov, submitted 9 Jul 75]

[Text] With the development of aviation and cosmonautics, much attention began to be devoted to development of methods of evaluating vestibular function. The caloric test, which is in wide use in physiological experiments and clinical practice, is one of the means of stimulating vestibular receptors. Studies have been published that deal with development of caloric test techniques that are optimal in one respect or other [8, 11, 13, 16] or with investigation of the intimate mechanisms of effects of a caloric stimulus [7, 10, 18, 19]. However, there are a number of unanswered questions with regard to characteristics of the stimulus acting on the cupulo-endolymphatic system in the course of the caloric test. For example, the extent to which calorization stimulates the vertical canals, as compared to the horizontal semicircular canals, is not known. This situation makes it difficult to comprehend the effects of caloric stimulation and diminishes the informativeness of this test.

Our objective was to conduct an experimental study of the intensity of vertical and horizontal caloric nystagmus as function of head orientation in a gravity field.

Methods

These studies were conducted on 17 males ranging in age from 16 to 27 years. We selected 13 head positions in relation to the gravitation vector (Figure 1). These positions were set by means of a special instrument that made it possible to orient vestibular elements in space. In 0° position, the subject stood vertically so that the plane plotted through the nasion and porion cranial points would be horizontal, while in the other positions he was on a tilting table. Various tilted positions of the table caused the subject to tilt at angles of 30, 60 and 90° from the zero position, forward and backward, in the sagittal plane (positions designated by the letter S), as well as to the right and left in the frontal plane (index F).

A series of 5 caloric stimulations was conducted with each subject, in different positions, at 15-min intervals. Caloric stimulation was delivered by irrigating the left ear with 300 ml water at 26.5° in 28 s. The experiment was randomized by the method of Latin squares [3].

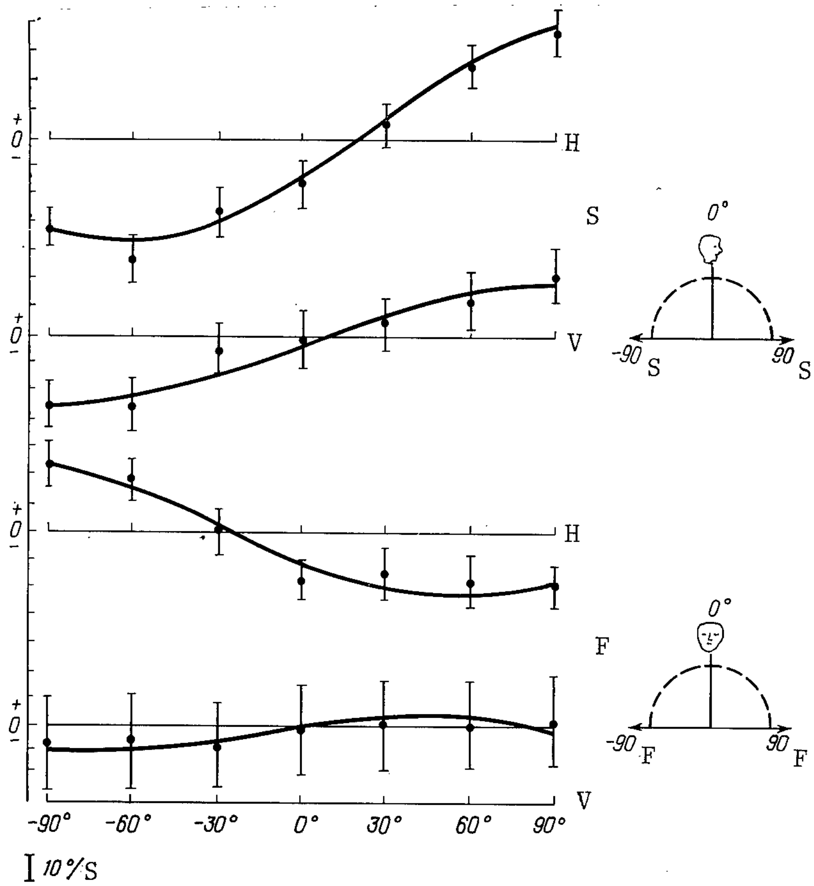


Figure 1. Rate of slow phase of nystagmus as function of head position in relation to gravitation vector; x-axis, angle of deflection of the head ϕ from zero position; y-axis, rate of slow phase of nystagmus

S) tilts in sagittal plane H) horizontal eye movements
F) tilts in frontal plane V) vertical " "

Solid line, rate as the function of position, described by interpolation formulas.

Nystagmus was recorded as an electronystagmogram (ENG). The potential occurring with horizontal eye movement was derived by means of electrodes 1 cm in diameter placed in the orbital canthi, and with vertical movement, by means of similar electrodes placed above and below the left orbit. Nystagmus was recorded on papertape using a 4EEG-3 4-channel encephalograph at paper feed rate of 30 mm/s and 0.2-12 Hz instrument throughput capacity.

On the ENG, we determined the segment with steepest fronts of slow phases of nystagmic beats and determined the maximum rate of the slow phase of nystagmus by averaging the rates of 5-10 adjacent beats. The rate of the slow phase of nystagmus directed up and to the right was considered negative and that directed down and to the left, positive. Maximum rate of nystagmus (Ω) as function of body position was described by means of functions such as: $\Omega = C_1+C_2 \text{ sine } \phi + C_3 \cos \phi$, where ϕ is the angle of head inclination in the corresponding plane. Coefficients C_1, C_2 and C_3 were determined by the least squares method [5].

Results and Discussion

Figure 2 illustrates samples of ENG recorded during the experiment. Eye movements in a horizontal direction and vertical direction are virtually always synchronized, i.e., the waves of nystagmic beats on both curves in a pair are situated one under the other. Visual analysis revealed that vertical nystagmus is usually more irregular than horizontal (see Figure 2,I). Vertical nystagmic beats are more often interrupted by slow eye movements in the vertical plane, or else occur against the background thereof. There were also wide differences in amplitudes of vertical components of nystagmic beats.

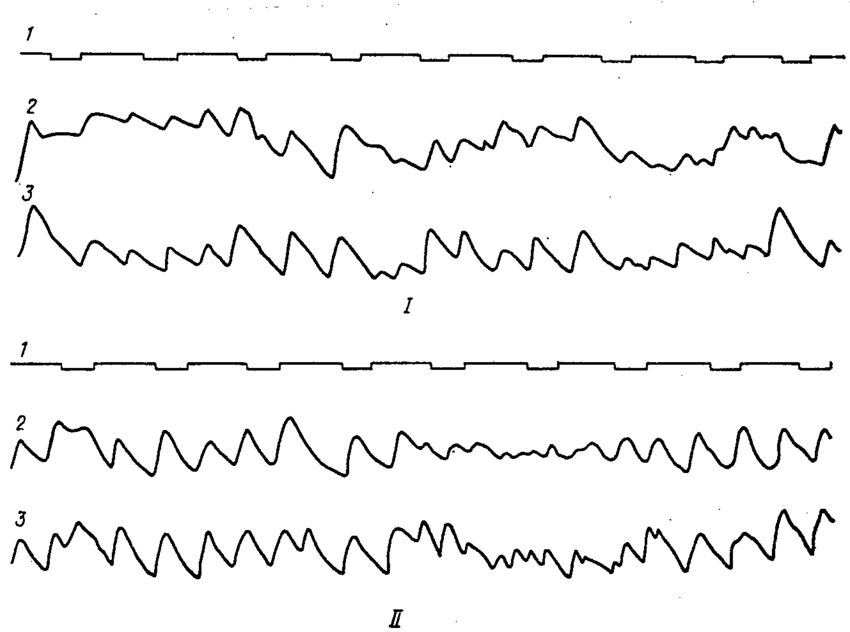


Figure 2. Samples of nystagmograms recorded in the experiment with caloric stimulation in the -90° position. Upward deflection of the curve corresponds to eye movement to the right or up

I) subject A
II) subject S.

1) time mark, 1 s
2) vertical nystagmus
3) horizontal nystagmus

In order to demonstrate the effect of the sequential number of caloric stimulation on intensity of nystagmus (magnitude of maximum angular rate of the slow phase), we calcuated the mean value of maximum angular rate for 13 positions for each caloric stimulation (Table 1).

Table 1. Value of maximum angular rate, mean of 13 positions ($\bar{\Omega}\pm2\sigma$)

Nystagmus	Sequential number of caloric stimulus				
	1	2	3	4	5
Horizontal	21,3±8,4	23,7±7,3	25,1±8,4	21,2±7,8	25,1±7,3
Vertical	12,3±5,0	13,8±5,1	20,8±7,6	15,7±5,3	16,6±5,3

Checking of the significance of differences in mean values of $\bar{\Omega}$ for different caloric stimulus numbers according to the criterion of Student revealed that these differences are statistically insignificant ($p>0.05$). Thus, in this experimental set-up, the sequential caloric stimulus number did not have an appreciable influence on the position effect.

Interpolation of the experimental data led us to the conclusion that, with the head tilted in the sagittal plane, the changes in maximum rate of the slow phase of horizontal and vertical nystagmus as function of angle of inclination can be described by the following formulas (see Figure 1, solid line; Table 2).

Table 2. Changes in maximum rate (Ω) of slow phase of nystagmus as function of tilt angle

Nystagmus	Plane	
	Sagittal	Frontal
Horizontal	$\Omega=-1{,}2+38{,}5\sin(\varphi-24°)$	$\Omega=2{,}1-25{,}0\sin(\varphi+34°)$
Vertical	$\Omega=-5{,}5+20{,}0\sin(\varphi+3°)$	$\Omega=-6{,}0+7{,}0\sin(\varphi+47°)$

Note: The value of Ω is given in degrees per second.

Tbe obtained formulas permit determination of head positions corresponding to maximum values of Ω, i.e., the positions in which horizontal or vertical nystagmus is more intensive. Thus, with tilts in the sagittal plane, horizontal nystagmus is more marked in supine position with $\phi = -66°$, while vertical nystagmus is more marked in the same position with $\phi = -93°$. Analogous values were obtained with tilts in the frontal plane: $\phi = -124°$ for horizontal nystagmus and $\phi = 0137°$ for vertical nystagmus.

In spite of synchronization of oscillations in the vertical and horizontal leads upon visual analysis of the ENG, the structures of the vestibulo-oculomotor arc that implements these two forms of movement are apparently

relatively independent. In the first place, vertical nystagmus is less regular and organized than horizontal; in the second place, vertical eye movements are the consequence of a change in afferent activity from the ampullar receptors of the vertical semicircular canals, while horizontal movements are related to receptors of the horizontal ones [2, 12].

We chose sinusoidal functions for approximation of the relationship between changes in rate of the slow phase of Barany nystagmus and tilt angle, since the magnitude of the stimulus affecting the semicircular canal at the specified distribution of temperatures in the cranial space is proportional to the cosine of the angle between the plane of the canal and direction of the gravitational vertical [9, 19]. Processing of experimental data revealed that this conception (see Figure 1) reflects rather well the actual relationships between changes in intensity of the nystagmic reaction. The positions determined, in which the nystagmic reaction is the strongest are qualitatively consistent with the data of authors [6, 11, 15] who strived to determine the optimum position of a subject, in the sense of severity of nystagmic reaction, during caloric stimulation. A more accurate quantitative comparison is not deemed feasible, because of the differences and vagueness of the subject's position in the gravity field that was used by different authors. The instrument used in our study for orientation of the head makes it possible to standardize this procedure, and adoption thereof in practice would permit more comprehensive comparison of the experimental results of different authors.

The fact that the values of the constant additive terms in the interpolation formulas are low, as compared to the amplitudes of sinusoidal functions, indicates that the effect of convection flow of endolymph, which depends on orientation of the head in relation to the acceleration vector, makes the main contribution to stimulation of the semicircular canals, whereas the contribution of other possible effects, unrelated to orientation, for example, shifting of endolymph due to expansion upon heating [1] or change in activity of receptor cells due to heating, is appreciably smaller.

There are contradictory opinions voiced in the literature concerning the possibility of stimulation of vertical semicircular canals by means of caloric stimulation. Although Fischer [14], K. L. Khilov [4] and others observed vertical and rotatory nystagmus, i.e., reactions of the vertical canals to the caloric test, many authors [15, 17, 20] believe that even if the vertical canals are stimulated, this occurs much less than for the horizontal ones.

The results of our experiment warrant the conclusion that it is basically possible to stimulate the vertical semicircular canals with the caloric stimulus, comparable in extent to stimulation of the horizontal canal, and this situation can occur with the subject in the same position, in relation to the gravitation vector.

BIBLIOGRAPHY

1. Gusev, V. M.; Kislyakov, V. A.; Levashov, M. M.; et al. in "Modeli neyronnykh struktur" [Models of Neuronal Structures], Moscow, 1970, pp 131-144.

2. Sentagotai, Ya. "The Role of Different Labyrinthine Receptors in Orientation of the Eyes and Head in Space," Leningrad, 1967.

3. Hicks, C. R. "The Main Principles Involved in Planning Experiments," Moscow, 1967.

4. Khilov, K. L. "Function of the Equilibrium Organ and Motion Sickness," Leningrad, 1969.

5. Khudson, D. "Statistics for Physicists," Moscow, 1967.

6. Aubry, M. "Otoneurology. Techniques and Interpretation of Labyrinth Tests," Paris, 1944.

7. Barany, R. MSCHR. OHRENHEILK., Vol 40, 1906, pp 191-297.

8. Barber, H. P., and Demanuele, F. ARCH. OTOLARYNG., Vol 94, 1971, pp 335-337.

9. Camis, M. "The Physiology of the Vestibular Apparatus," Oxford, 1930.

10. Cawthorne, T., and Cobb, W. A. ACTA OTO-LARYNG. (Stockholm), Vol 44, 1954, pp 580-588.

11. Coats, A. C., and Smith, Y. S. Ibid, Vol 63, 1967, pp 515-532.

12. Cohen, B.; Suzuki, J.; and Bender, M. B. ANN. OTOL. (St. Louis), Vol 73, 1964, pp 151-164.

13. Fischer, M. H. KLIN. WSCHR., Vol 12, 1933, pp 1925-1930.

14. Idem, PFLUG. ARCH. GES. PHYSIOL., Vol 213, 1926, pp 74-98.

15. Fitzgerald, G., and Hallpike, C. S. BRAIN, Vol 65, 1942, pp 115-137.

16. Jongkees, L. B. W. ARCH. OTOLARYNG., Vol 49, 1949, pp 594-608.

17. Hinshliffe, R. SOUND, Vol 3, No 4, 1969, pp 92-97.

18. Schmaltz, D. G. PROC. ROY. SOC. MED., Vol 25, 1932, pp 359-381.

19. Steer, R. W.; Li, Y. F.; Young, L. R.; et al. in "Third Symposium on the Role of the Vestibular Organs in the Exploration of Space," Washington, 1967, pp 409-420.

20. Veits, C. ACTA OTO-LARYNG. (Stockholm), Vol 13, 1929, pp 94-115.

UDC: 613.483:629.78.048

A STUDY OF THE PULSED METHOD OF LAUNDERING

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian No 5, 1977 pp 80-85

[Article by B. A. Adamovich, V. V. Borshchenko, Ya. N. Vernikov, A. G. Prishchep and A. P. Rogatovskaya, submitted 20 May 75]

[Text] With regard to providing all the necessary conditions for long-term manned space flights, it becomes necessary to equip space stations with washing machines and wringers as part of the sanitary and housekeeping equipment. The absence of gravity does not permit the use of existing combination machines (washing and wringing) in which the drum method of laundering is combined with centrifugal spinning.

In weightlessness, only washing machines, in which mechanical action on laundry occurs by means of forced pumping of soap is provided, can be used. For this reason, machines in which the laundering process takes place in the form of period compression of the elastic container into which the laundry is placed could meet the requirements. Machines of this type have many features in common with wringers that operate on the compression principle, which have become popular in recent times.

It would be rational to combine in the same unit a device to pump the washing solution through the laundry during the washing cycle and spinning water out by means of compression in a washing machine that would be suitable for space flight conditions. The absence of data in the literature concerning the design parameters of washing and spinning devices of this type, as well as technological operating modes made it necessary to conduct a series of experimental studies.

Methods

These studies were conducted on a special device with energy consumption of 400-700 W [1]. This machine (Figure 1) consists of steel chamber *1* that is cylindrical in shape, to which flexible tub *2* is hermetically attached. Chamber *7* is secured to the bottom of tub *2*. In operating position, the tub is closed by a double cover *3* consisting of two main parts: perforated and hermetic covers. As is the case under actual conditions, laundering is effected by the pulsation method: periodic compression and expansion of tub *2*,

which contains the laundry to be washed. The elastic tub is compressed under the action of compressed air passing into chamber *1* over pneumatic duct *6*. To augment the pumping effect in the washing process, the washing solution (or rinse water) is circulated. With compression of the tub, the washing solution being pumped through the laundry is removed through the perforated cover and passes into an intermediate reservoir *5* over hose *4*. The tub is expanded under the influence of compressed air fed into reservoir *5*. The washing solution thus expelled returns to the tub through a drum [collector] and hose [flexible sleeve] expanding the drum and repeating the pumping effect. Thus, the washing solution is pumped twice through the laundry in one cycle (compression and expansion of the tub).

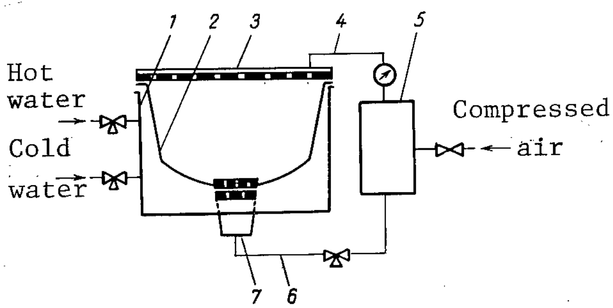


Figure 1.
Diagram of model of machine for pulsed laundering. Explanation given in the text.

During each technological operation, laundry was loaded in the tub and the required amount of washing solution prepared and warmed in advance was delivered in the tub. The washing solution was obtained by dissolving detergent [or soap] in tablet form in hot water, in a special device, followed by delivery thereof into the tub through a three-way valve. Lid *3* is shut and, upon command from the control console, slide valves were switched on, which opened the appropriate valves. Compressed air was delivered over duct *6* into the working chamber *1*, compressing tub *2*. The washing solution, after being pumped through the laundry and perforated cover *3* entered intermediate reservoir *5*. After the preset time had elapsed, the compression cycle stopped and the slide valves were reset; this was associated with closing and opening of the appropriate valve. Chamber *1* was connected with the atmosphere, the pressure in it dropped and tub *2* began to expand under the influence of rigid deformation. At the same time, compressed air was fed into chamber *5* through the opened valve and, expelling the washing solution, directed it into the tub. The washing solution, entering the tub at considerable velocity, was actively pumped through the laundry, intensifying the washing and rinsing processes. Thus, fluid was pumped twice per cycle through the laundry: upon compression and expansion of the tub.

Upon completion of the expansion cycle, a command was issued to switch over the slide valves to the original position, which led to closing and opening

of the required valves. Compressed air from reservoir *5* was released into the atmosphere at will [or random] while pressure began to be created again in chamber *1*, and the cycle was repeated.

Upon completion of each technological operation the used washing solution was removed from the machine, i.e., there was intermediate wringing of laundry under the wandering pressure. The slide valves were then moved to expand tub *2*, and fresh washing solution was directed into it from the measuring tank, and the next technological operation began. The used solution with detergent components was passed into the system of regeneration of sanitation water.

The design of the experimental machine made it possible to vary different parameters of the process over a wide range, and a set of checking and measuring equipment was used to determine their effects on laundering quality.

The necessary program of investigations was conducted with the above device, including determination of both the parameters of this laundering method and medicotechnological evaluation of the machine's capabilities.

In the course of the experiment, the quality of laundering was characterized by the magnitude of washing capacity M determined by the following formula:

$$M = \frac{W_{ca} - W_{bw}}{W_i - W_{bw}} \cdot 100\%,$$

where W_{ca} is whiteness of a control sample of fabric after washing; W_{bw} is whiteness of control sample of fabric before washing and W_i is initial whiteness of the material of which the control sample was made.

Washing capacity was determined according to artifically soiled control samples, the whiteness of which was evaluated before and after laundering with a photometer. In the course of the experiment, 3-4 control samples were put in the model along with naturally soiled laundry.

Results and Discussion

As a result of experiments conducted to determine the quality of laundering as function of duration of the process in the first wash (phase) at different temperatures of washing solution, it was established that the curves describing this function (Figure 2) are similar in nature. The intensity of the process, measured by increment of washing capacity per unit time is rather high at first, then diminishes. This is attributable to the fact that soil mildly bound with the fabric is removed rather rapidly under the influence of the detergents and mechanical action. As for most of the soil, firmly bound with the fabric, the low temperature of the solution in the first wash does not break down these bonds, and the mechanical action is not enough to remove it. For this reason, the laundering effect obtained in the first wash is relatively small, and increased productivity of the process does not have an appreciable effect on the quality of washing.

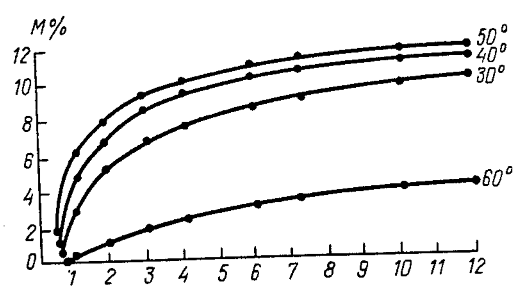


Figure 2.
Quality of washing as function of duration of the process in the first wash at different temperatures

According to the illustrated graph, a higher temperature of the washing solution improves the quality of laundering much more. Studies revealed that soil begins to set, i.e., become fixed on the fabric like paint, if the laundry is not presoaked, at solution temperature of 50°, as indicated by the considerably increased scatter of values characterizing washing capacity in the course of this experiment. With subsequent elevation of temperature of washing solution, the setting process is intensified and washing quality diminishes sharply. For this reason, in spite of the fact that when the temperature of the solution in the tub is raised from 40 to 50° and there is some increase in laundering effect, it was deemed purposeful to use washing solution at a temperature of 40° in the first wash to avoid the possibility of stain setting.

At the temperature we selected, the optimum washing time in the first wash presents a distinct tendency toward decrease in intensity of the process as function of time. While the washing capacity increases to 7.7% in the first 2 min, i.e., by a mean of 3.85% per min, this increment diminishes on the average to 0.8% in the next 2 min, and drops to 0.4% in the interval between the 4th and 6th min. According to Figure 2, the sharp decrease in intensity of the process is observed after the 3d min. However, for maximum utilization of washing agents and improved conditions of regeneration of sanitation and housekeeping water to be used many times, it is desirable to extend washing time to 6 min. Further extension of this operation is not rational, since the increment of washing capacity and, consequently, utilization of washing agents become negligible in the interval between the 6th and 8th min, i.e., 0.25%/min.

Thus, with the established time and temperature of the first washing operation, a washing capacity of 10.1% is obtained. Since the obtained washing effect is not satisfactory and further extension of this operation is not desirable, it was deemed necessary to transfer the process to the second washing cycle ["tub"].

Unlike the first wash, the temperature of the second wash can be at a maximum, since presoaking and heating the laundry to 40° in the first wash eliminated the danger of setting of protein-containing soil. As we know, with increase in solution temperature in the wash tub there is an increase in interaction

of washing solutions and soil, as well as decrease in surface and interphase tension of fluid, which increases the mechanical effect on the laundry. In view of this circumstance, we used a temperature of 90-95% in the second wash cycle. It presents no major difficulty to produce such temperatures onboard the craft.

Studies revealed that maximum removal of soil is observed with this temperature level. While the washing capacity constituted 37% in a 95° tub after 10 min of washing, at a temperature of 85° of the washing solution the washing capacity constituted 33.4% in the same time, or 3.6% less.

A curve was plotted from the results of the experiment, characterizing the cleansing effect as function of duration of the second wash at the selected temperature (Figure 3). This curve is very similar to the one illustrated in Figure 2, and it shows a substantial increase in intensity of the process, as compared to the first wash, which is attributable to the above-mentioned causes. While the maximum washing capacity obtained in the first wash at 40°temperature constituted 11%, in the second it was 37.7%, i.e., it was 3.4 times greater. We selected 10 min as the time of the second wash for maximum utilization of detergents.

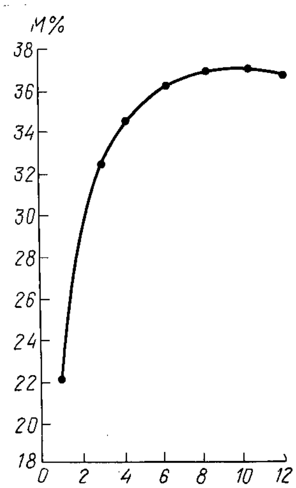


Figure 3.
Washing capacity as function of second washing time

The water modulus affects the washing results appreciably in the pulsed method of laundering, since water is in this instance an emulsifying medium and carrier of mechanical energy as well. A study of this function for both wash cycles revealed that the curves that characterize it have a distinct polar [extreme] appearance (Figure 4). This is attributable to the following: With low values of the water modulus, most of the period of compression of the flexible tub is associated with an increase in density of the bundle of laundry, since there is not enough water being pumped through the laundry during expansion of the tub to separate it. Laundering of items within the bundle is virtually stopped.

With increase in water modulus, the quality of washing improves, and the curves reach a maximum with argument value of 5 dm^3/kg laundry. With further increase of the tested parameter, the quality of laundering worsens, since with an excessively high modulus most of the period of compression is referable to removal of free moisture, as a result of which there is a decrease in degree of wringing of the laundry and, consequently, mechanical effect on the fabric.

One should use an extreme water modulus for the first wash and one close to the "critical" for the second, i.e., 4.5 dm^3/kg, since it is no longer necessary to soak the fabric, while the washing capacity increases negligibly with increase in modulus from 4.5 to 5 dm^3/kg. The overall utilization of hot water constitutes 25 dm^3/kg.

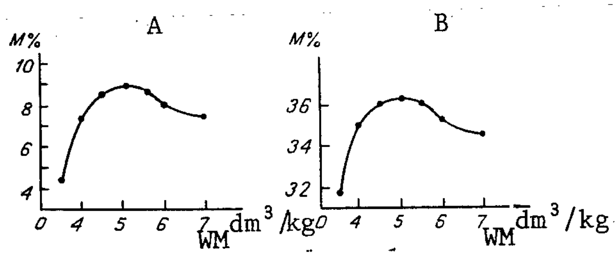


Figure 4.
Washing capacity as function of water modulus (WM)

A) first wash
B) second wash

In view of the fact that in the course of regeneration of utilized sanitation and housekeeping liquid by the method of coagulation followed by filtration and additional treatment there are difficulties in extracting synthetic surfactants [3], we used compositions on a fatty base with active additives in accordance with the formula for the Spetsial'nyy washing agent. This formula was consistent with the requirements imposed on personal hygiene items for the crews of long-term space flights. However, in view of the distinctions of specific life-support systems, it is deemed desirable to continue work on refinement of washing agents in the direction of strengthening components with antibacterial properties.

The results of analysis of clinicophysiological condition of the skin and some of the other organs and systems of subjects who wore the laundry items treated as described above in the course of lengthy pressure chamber experiments lead us to believe that the low-frequency pulsation method of laundering is acceptable for maintaining the necessary sanitary conditions. The parameters of hygienic processing [laundering[proposed in the course of the present studies can be recommended for the design of combined washing and wringing machines of this type.

BIBLIOGRAPHY

1. Vernikov, Ya. N.; Minayev-Tsikanovskiy, V. A.; and Nemzer, A. Yu. "Author's Certificate No 274082," in OTKRYTIYA [Inventions], No 21, 1970, p 22.

2. Nemzer, A. Yu., and Vernikov, Ya. N. KOMMUNAL'NYYE MASHINY [Communal Machines], Vyp 1, 1969, p 27.

3. Chizhov, S. V., and Sinyak, Yu. Ye. in "Problemy kosmicheskoy biologii" [Problems of Space Biology], Moscow, Vol 24, 1973, p 99.

CLINICAL RESEARCH

UDC: 616.33-002.44-057.9:656.7]-07

SIGNIFICANCE OF THE 'PERCUSSION' SYMPTOM IN DETECTION OF PEPTIC ULCERS IN FLIGHT PERSONNEL

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian No 5, 1977 pp 85-87

[Article by Ye. A. Fedorov (deceased) and V. D. Vlasov, submitted 4 Oct 76]

[Text] In spite of strict medical screening and annual certification by medical flight commissions, the incidence of peptic ulcer ranges from 0.16 to 5% among flight personnel. This disease is one of the frequent causes of professional disqualification [1, 2].

It is difficult to diagnose peptic ulcers in flight personnel because of possible dissimulation, atypical or asymptomatic course [3, 4]. Sudden onset of complications of this disease (hemorrhage, perforation) during a flight could lead to serious consequences. Exacerbation of peptic ulcer in flight personnel is observed in 28.2-52.5% of the cases [5].

All of the foregoing is indicative of the urgency of early detection of this disease in flight personnel and treatment thereof. For this purpose, we tested the diagnostic value of the "percussion" symptom in the right subcostal region at the height of inspiration.

Many authors have indicated the diagnostic significance of local percussory tenderness and muscle tension during percussion with the index finger of the abdominal wall, with regard to detection of peptic ulcer [6-13]. Thus, Ye. P. Zamarayev [12] has shown that the symptom of percussory tenderness was positive with exacerbation of the disease in 94.9% of the patients, and most of them presented a marked pain syndrome.

Methods

We used percussion according to Mendel, as modified by Ye. A. Fedorov, for detection of pathology of the liver and biliary ducts. The test was performed in the following manner: The physician placed his left palm on the abdominal rectus muscles above the pubic bone, slightly pressing on them, while he used the right fingertips to percuss the anterior abdominal wall in the right and left subcostal regions (symmetrically) at rest and

particularly in maximum inspiration, with the patient lying in a relaxed position. For proper evaluation of this symptom, the presence of tenderness and degree of muscular contraction felt with the left hand on the left and on the right were compared at rest and in maximum inspiration. Absence of tenderness and muscular contraction was typical for a negative symptom. In the presence of tenderness in the right subcostal region and contraction of the right abdominal rectus muscle (considerably more often in maximum inspiration), the symptom was considered positive. A distinction was made between mild, moderate and markedly positive "percussion" symptom, according to the severity of this reaction. Tenderness and muscular tension of varying degrees were determined together or separately.

The muscular reaction, which is not controlled by the individual, is of great diagnostic value. It has been noted in a textbook [14] that this procedure can be used for the detection of latent pathology of the stomach, duodenum and particularly the liver and biliary ducts.

We tested the diagnostic value of a positive "percussion" symptom in detection of peptic ulcer. We examined flight personnel ranging in age from 19 to 45 years, 144 of whom suffered from peptic ulcer, mainly localized in the duodenum; 29 people made up a control group. Peptic ulcer at an exacerbation stage was demonstrated in 75 cases and in remission, in 69.

Results and Discussion

It was established that mild and moderate positive reactions to percussion in the right subcostal region at maximum inspiration, most often observed in the healthy individuals of the control group have no practical significance. Among those with pepetic ulcer, a markedly positive reaction to percussion was observed in 22 cases (29.3%) at the exacerbation stage, 10 (14.5%) in remission and 1 (3.4%) in the control group. Thus, the positive reaction was demonstrated almost twice as often with exacerbation of ulcer as in remission. The difference in incidence of markedly positive "percussion" symptom in flight personnel with pepetic ulcer at the stage of exacerbation or remission, as compared to the control group, is statistically reliable (t = 4.2 and 2.1, respectively).

It must be noted that eight individuals, who concealed their complaints or presented an atypical course of the disease, were suspected of having peptic ulcer only because of the markedly positive "percussion" symptom. Subsequent roentgenological examination confirmed the diagnosis, and in six of these cases the ulcer was at a stage of exacerbation.

We submit a case history:

> Candidate R, in the 3d year of flying schoool, 20 years of age: The medical flight commission deemed him to be in good health. On 2 Jul 1968, during a test flight with an instructor, the student lost consciousness briefly, and for this reason he was referred to the hospital for an examination. He presented no

complaints. He is a moderate smoker and does not drink. The patient presents regular body conformation and his nutrition is satisfactory. The integument and visible mucous membranes are of the usual color. The thyroid and subcutaneous lymph nodes are not enlarged. Pulse is 66-68/min and rhythmic. Arterial pressure is 130/80 mm Hg. The heart and respiratory organs present no distinctions. The tongue is slightly coated near the root. The abdomen is soft, not tender to palpation. The liver and spleen are not enlarged. Viscerocardiac reflex is negative upon pressure applied to the region of the solar plexus. Percussion in the right subcostal region at maximum inspiration is somewhat tender, with marked muscular contraction. No changes referable to the genitourinary system. Nervous system: general hyperhidrosis, acrocyanosis of the hands, tremor of the eyelids and extended fingers, persistent red dermographism, emotional instability. Roentgenological examination of the stomach revealed a hypersecretory layer of fluid, irritation of the duodenal bulb with an ulcer "niche" on the anterior wall. Upon eliciting his history, it was established that 5 years prior to enrolling at the school the patient was bothered with periodic gnawing pain in the epigastric region for 2 months, for which he was treated at a hospital with beneficial effects. For the next 2 years he occasionally suffered from heartburn. He did not seek medical attention. After successful treatment for the ulcer, the medical flight commission deemed him unfit for flight training.

The tenderness and muscular contraction of the "percussion" symptom is apparently based on a reflex from the involved organ and irritation of the solar plexus. Demonstration of a markedly positive "percussion" symptom in the presence of peptic ulcer is related, to some extent, to stasis in the liver. Thus, there was significant decrease in muscular contraction and tenderness after duodenal catheterization, which was performed on 14 individuals. This assumption is confirmed by the data in the literature concerning the frequent involvement of the liver in the pathological process in the presence of peptic ulcer [15-18]. It was noted that this symptom becomes negative or less marked after treatment of the ulcer.

Thus, when examining flight personnel, in addition to clinical methods one must also use the above procedure, which is objective, can be readily performed under any conditions and is of definite value to medical flight certification. Demonstration of a severely positive "percussion" symptom in the right subcostal region at maximum inspiration serves as an indication for clinical and roentgenological examination of the stomach and duodenum to rule out peptic ulcer.

BIBLIOGRAPHY

1. Spiegel, F. S. AEROSPACE MED., Vol 30, 1959, pp 476-480.

2. Malyshkin, Ye. T., and Gel'man, B. L. VOYEN.-MED. ZH. [Military Medical Journal], No 7, 1961, pp 57-60.

3. Orlov, N. V. Ibid, No 5, 1969, pp 62-64.

4. Vlasov, V. D. "Some Problems of Symptomatology, Diagnostics, Treatment and Expert Certification of Peptic Ulcer in Flight Personnel," candidatorial dissertation, Leningrad--Moscow, 1974.

5. Sais, J., and Galban, P. REV. CPS. SANTE ARMEES, Vol 65, 1965, pp 653-658.

6. Mendel, F. MUNCH. MED. WSCHR., Vol 50, 1903, pp 554-555.

7. Razdol'skiy, I. Ya. VRACH. GAZETA [Medical Gazette], No 22, 1927, pp 1635-1641.

8. Luriya, R. A. "Pathology of the Esophagus and Stomach," Moscow--Leningrad, 1941.

9. Smotrov, V. N. "Peptic Ulcer and Treatment Thereof," Moscow, 1944.

10. Flekel', I. M. "Peptic Ulcer," Moscow, 1958.

11. Badyl'kes, S. O. "Gastric and Duodenal Ulcers," Moscow, 1956.

12. Zamarayev, Ye. P. "Tenderness to Percussion in Symptomatology of Peptic Ulcer," author abstract of candidatorial dissertation, Kuybyshev, 1963.

13. Ryss, S. M., and Ryss, Ye. S. "Peptic Ulcer (Uncomplicated Form)," Leningrad, 1968.

14. "Methods of Examination for Medical Flight Certification," Moscow, 1972.

15. Sinitsina, F. F. "Changes in Condition of the Biliary Tract and Some Liver Functions in the Presence of Peptic Ulcer," author abstract of candidatorial dissertation, Odessa, 1955.

16. Rozmarin, Sh. V. "Condition of the Biliary Tract of Patients With Peptic Ulcer," author abstract of candidatorial dissertation, Kuybyshev, 1961.

17. Polyak, Ye. Z. TRUDY 1-GO MOSKOVSK. MED. IN-TA [Works of the First Moscow Medical Institute], Vol 39, 1965, pp 131-145.

18. Mayanskaya, K. A. "Functional Correlations Between Digestive Organs, Clinical Observations," Leningrad, 1970.

UDC: 616.12-009.86-057:656.7]-085.851.111-039.71

AUTOGENIC TRAINING USED FOR SELF-REGULATION OF CARDIOVASCULAR FUNCTION AND PREVENTION OF NEUROCIRCULATORY DYSTONIA IN PILOT CANDIDATES

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian No 5, 1977 pp 88-90

[Article by V. S. Lozinskiy, submitted 10 Aug 76]

[Text] Sufficient experience has already been acquired in using methods of autogenic training [1-7]. The studies of a number of authors [8-11] revealed that autogenic training permits regulation not only of the general mental condition and function of different systems, but internal organs.

The objective of this work was to investigate the possibility of use by pilot candidates of autogenic training to regulate cardiovascular function in the presence of transient functional disturbances. As we know, candidates who repeatedly present high arterial pressure and fast pulse rate before flying or in the course of routine medical certification, are rejected by physicians from flying and referred for further work-up to hospitals and medical centers. As a result, such candidates, who concentrate more and more on the condition of their health, aggravate the functional changes in the cardiovascular system, and for this reason prevention of neurocirculatory dystonia in pilot candidates is one of the important tasks of aviation physicians.

Methods

There were 27 candidates under observation; they repeatedly presented high arterial pressure and pulse rate in the course of routine medical certification and periodic physicals. All of them had undergone a work-up at medical centers and hospitals.

Before starting instruction in methods of psychophysiological self-regulation, all of the candidates presented high arterial pressure (from 135/70 to 160/85 mm Hg) and 14 of them also had a fast pulse (over 90/min).

The classes in autogenic training were conducted on an ambulatory basis in 2 groups, 3 times a week, each lasting 45-60 min in a "coachman" position. The format of the classes was taken from the "neurovascular variant of

autogenic training" [feedback?][12]. However, in teaching "calming" exercises, we excluded sensations of heaviness in the hands, legs and entire body.

Instruction began with training for general calming down, muscular relaxation and ability to induce a sensation of heat in the right hand. For this purpose we used the variant of autogenic training modified by A. T. Filatov [13].

During the classes, all of the candidates felt well. Many of them succeeded in inducing a heat sensation in the right hand in the very first class, which stimulated active independent work. During the classes, we pronounced the main autosuggestion formula, then waited 3-5 s for the candidates to repeat it, then whispered a comment (suggestion).

1. "I want very much for my right hand to get warm."

Suggestion: "Pretend that your hand is wrapped in a warm down scarf. The hand is beginning to warm up, it is getting hotter. You feel a pleasant warmth. The sensation of warmth is increasing."

2. "I want very much for my right hand to get warm."

Suggestion: "You do indeed feel the appearance of pleasant warmth in your right hand. With each minute, the sensation of heat is becoming more and more marked. The hand is becoming warm. There is the sensation that the hand is massive. The appearance of the sensation of heat is due to the fact that you have willed dilatation of the blood vessels. Blood has rushed to the right hand. You feel how the hand is warming more and more from the influx of blood. It is becoming more massive than the left and, at the same time, warmer."

3. "I want my right hand to get warm."

Suggestion: "Your autosuggestion is working. The sensation of heat is ever increasing. The right hand is permeated with pleasant warmth. The warmth involves the right hand and is beginning to rise. The warmth is moving to the arm. The sensation of warmth is increasing. The sensation of warmth is increasing."

4. "Let my right hand get warm..."

Suggestion: "Your right hand is getting warmer and warmer. You have willed dilatation of blood vessels in the right hand. Blood has rushed to the right hand. You can feel how the skin on the right fingers is distending because of the blood."

5. "My right hand has become warm...."

Suggestion: "The right hand is increasingly filled with pleasant warmth. The warmth is spreading to the right arm. The entire right hand is warm."

6. "The right hand is warm...."

Suggestion: "Your right hand is warm, as if you had immersed it in hot water. The warmth involves the right hand uniformly."

After obtaining dilatation of the vessels of the right hand, the candidate was asked to imagine that the sensation of heat is going away, instead of relaxation there is a feeling of wakefulness and lightness, like after a good, pleasant rest. After the exercise, we explained to the candidate that the ability to voluntarily dilate blood vessels and slow down the heart rate enables him to develop skills in self-regulation of cardiovascular activity and thereby normalize arterial pressure and pulse indices. For better demonstration of the effectiveness of autosuggestion, we measured arterial pressure and pulse rate before the exercises and during autosuggestion of warmth in the right hand. Even minor changes in pressure and pulse rate appeared to be evidence of the effectiveness of the autosuggestion sessions.

The results were particularly effective when the candidates measured one another's pressure and counted the pulse. This developed more confidence in them as to the possibility of successful use of psychophysiological self-regulation techniques.

In the third session, we began to teach the candidates to induce the sensation of heat in the left hand and legs. The content of autosuggestion and methods of instruction were similar to those used in teaching them to dilate the vessels of the right hand. After four sessions, the candidates were able to independently induce the sensation of heat in the hands and legs, so that we devoted the last two classes to instruction on controlling cardiovascular function and respiration.

We used the procedure proposed by G. S. Belyayev [2], with potentiation of autosuggestion according to A. T. Filatov [13]: "I am mentally feeling the left fingers in turn; they are filling with a sensation of pleasant, dense warmth; the warmth is gushing into the left hand, filling the entire arm to the shoulder; the arm is swelling from the pleasant warmth; the vessels are relaxed and dilating; the warmth is moving over the shoulder to the left half of the chest; the heart is bathing in warmth; warmth is rushing through the heart; the heart is luxuriating, it is calm and feels pleasant."

The physician reinforces the autosuggestion: "Pleasant calm spreads over the entire body. You feel pleasant calm in the chest. The heart is functioning calmly, rhythmically, automatically. You feel the effectiveness of your suggestion. The heart contracts less often and rests more. The muscle of the heart is resting. The heart has calmed down." After the group of autosuggestions for the heart, the candidate proceeds with: "My breathing is even, rhythmic and calm."

And the physician potentiates the autosuggestion: "You feel how rapidly your autosuggestion is effective. Indeed, breathing is becoming calm, even and rhythmic. It is easy, free and pleasant to breathe."

The classes ended with an explanation that the ability to relax breathing and cardiac function aids in relaxation of physiological reactions and significant lowering of arterial pressure and pulse rate. After the classes, the candidates were instructed to exercise independently at least twice a day; the importance of exercises before going to sleep, before and after emotional loads was particularly stressed.

The candidates continued with the training independently, and individual consultations were provided when necessary.

Results and Discussion

Numerous control readings of arterial pressure (AP) and pulse rate (PR) 1-6 months after the classes began revealed that there was stable normalization of AP and PR in 22 candidates (AP did not exceed 130/75 mm Hg and PR, 78/min); a decline of AP and PR to normal levels was noted in 3 candidates only after a 5-10-min period of calming down; in 2 candidates the AP reverted to normal, but PR often reached 86-90/min and, in spite of performing the "calming down" variant, there was no decrease of PR.

BIBLIOGRAPHY

1. Alekseyev, A. V. "Psychoregulatory Training (Part 2, Mobilization," a methodological letter, Moscow, 1969.

2. Belyayev, G. S., and Mazhbits, A. A. "Autogenic Training in the Treatment of Neurosis," methodological letter, Leningrad, 1968.

3. Gissen, L. D. in "Voprosy psikhoterapii v obshchey meditsine i psikhonevrologii" [Problems of Psychotherapy in General Medicine and Neuropsychiatry], Khar'kov, 1968, pp 460-461.

4. Ivanov, N. V. in "Aktual'nyye voprosy psikhiatrii i nevropatologii" [Pressing Problems of Psychiatry and Neuropathology], Moscow, 1963, pp 379-384.

5. Lobzin, V. S., and Kulagin, Yu. M. "Autogenic Training in the Practice of a Medical Officer," methodological aid, Leningrad, 1968.

6. Mirovskoy, K. I., and Shagam, A. N. in "Psikhoterapiya v kurortologii" [Psychotherapy in Balneology], Kiev, 1966, pp 235-238.

7. Romen, A. S. "Autosuggestion and Its Effect on the Human Body," Alma-Ata, 1970.

8. Ikonnikov, V. A. in "Psikhicheskaya samoregulyatsiya" [Mental Self-Regulation], Alma-Ata, 1973, p 151.

9. Lebedinskiy, M. S. "Essays on Psychotherapy," Moscow, 1971.

10. Nachenskaya, E. M.; Ikonnikov, V. L.; and Levenkov, A. V. TRUDY GOR'KOVSK. MED. IN-TA [Works of Gor'kiy Medical Institute], Vyp 31, 1969, pp 245-248.

11. Romen, A. S. in "Psikhonevrologiya. Psikhoterapiya. Psikhologiya" [Neuropsychiatry. Psychotherapy. Psychology], Alma-Ata, 1972, pp 203-206.

12. Perekrestov, I. M. TRUDY PERMSK. MED. IN-TA [Works of Perm' Medical Institute], Vyp 1, Vol 80, 1968, pp 71-81 .

13. Filatov, A. T. "Emotional-Volitional Training of Bicyclists," Kiev, 1975, pp 18-25.

BRIEF REPORTS

UDC: 612.881-057:629.78

INVESTIGATION OF SPACE PERCEPTION BY THE CREW OF THE EXPERIMENTAL SOYUZ-APOLLO MISSION

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian No 5, 1977 pp 90-91

[Article by L. N. Kornilova, G. D. Syrykh, I.K. Tarasov and I. Ya. Yakovleva, submitted 31 May 76]

[Text] We made a study of the function of perception of spatial coordinates in order to obtain objective, quantitative information about perception before and after space flights, as well as to investigate the correlations between indices of accuracy of perception of spatial coordinates and intensity of subjective reactions.

Methods

We used the Soviet Vertikal' instrument to test perception of spatial coordinates. A detailed description of the basic system of the technique, criteria of normal and substance of parameters evaluated were published previously [1, 2].

Five- to seven-fold testing was performed twice before the mission (15-16 and 3 days prior to it) and twice after the mission (1st and 4th postflight days). The tests were performed in three positions: seated and lying on the right and left sides. At the same time, we recorded the time spent by the subjects to reconstruct a lighted slit in vertical or horizontal position.

Results and Discussion

In cosmonaut V. N. Kubasov, the indices of accuracy of perception of spatial coordinates were in the physiological range in the two background tests at rest. In cosmonaut A. A. Leonov, the first background test in seated position revealed an error of perception of spatial coordinates beyond the physiological range of scatter. No asymmetry was noted in distribution of indices with the cosmonauts lying on their side.

Postflight testing of cosmonaut A. A. Leonov failed to demonstrate appreciable changes in the perception system: the fluctuations of error were in the range of normal physiological scatter.

On the 1st postflight day, cosmonaut V. N. Kubasov presented an increased error of perception of spatial coordinates in seated position (twice as high as normal), as well as appearance of asymmetry which, however, did not exceed the top range of normal. Testing on the 4th postflight day revealed a decrease in errror to the bottom range of normal, with retention of a tendency toward asymmetry.

Analysis of time parameters required to perform the task revealed negligible increase in both cosmonauts on the 1st postflight day.

Investigation of the correlations between indices of accuracy of spatial perception on the ground at rest and severity of subjective reactions in flight revealed the following: A. A. Leonov, who had marked illusory reactions (inversion illusion) during the mission, presented a higher error factor in perception of spatial coordinates in the background tests.

The mildness of Aubert's phenomenon in both cosmonauts, both before and after the mission, can apparently be attributed to regular preliminary conditioning of the vestibular system and perception during exercises dealing with spacecraft docking in the course of their occupational training.

BIBLIOGRAPHY

1. Bokhov, B. B.; Kornilova, L. N.; and Yakovleva, I. Ya. KOSMICHESKAYA BIOL. [Space Biology], No 6, 1973, pp 51-56.

2. Idem, Ibid, No 1, 1975, pp 51-56.

3. Kliks, F. "Problems of Psychophysics of Space Perception," Moscow, 1965.

4. Kurashvili, A. Ye., and Babiyak, V. I. "Physiological Functions of the Vestibular System," Leningrad, 1975.

UDC: 612.85-06:612.223.1

EFFECTS OF HIGH CONCENTRATIONS OF CARBON DIOXIDE ON FUNCTION OF THE HUMAN ACOUSTIC ANALYZER

Moscow KOSMICHESKAYA BIOLOGIYA I AVIAKOSMICHESKAYA MEDITSINA in Russian No 5, 1977 pp 91-92

[Article by Yu. V. Krylov, submitted 23 May 75]

[Text] The rapid development of technology is making increasing demands with regard to reliability of the "man--machine" system, particularly when the factors involved are at extreme levels. For this reason, in the last decade, there has been increased interest in the study of function, in particular of the auditory analyzer of man, under extreme conditions, particularly since the organ of hearing is, according to the data of various researchers, superior to the endurance of the visual analyzer, with respect to accelerations, hypoxia, thermal factors, etc. [1, 2, 5, 6].

In this work, an effort was made to investigate the distinctions of the human acoustic analyzer in the presence of a high concentration of carbon dioxide in inhaled air (from 1 to 8%). The thresholds of auditory sensibility for airborne conduction were tested at frequencies of 125-10,000 Hz on 15 healthy males ranging in age from 19 to 30 years. Audiometry was performed before, during and 5-30 min after the experiment.

It was shown that exposure of man to an atmosphere with CO_2 concentration of 1 to 2% for many days does not lead to a statistically reliable change in hearing thresholds [3]. The same findings were obtained with exposure of man to an atmosphere with up to 3% CO_2.

The first changes in auditory thresholds were obtained when the subjects were exposed for a long period of time to a respiratory gas mixture with 4-4.5% CO_2 (Table 1).

It is important to note that with increase in CO_2 concentration to 5% we observed deterioration of hearing, not only at high (2000 Hz), but low (125, 250 Hz) frequencies; however, even these changes occur after lengthy (several hours) exposure. This type of reaction is basically retained with further increase in CO_2 concentration to 5.5-6%.

Table 1. Data on hearing thresholds after many hours of exposure of subjects to an atmosphere containing 4-4.5% CO_2

Index		Tested frequencies, Hz									
		125	250	500	1000	2000	3000	4000	6000	8000	10 000
Increase in hearing threshold, dB	M	9	10	10	11	13	14	15	16	15	18
	$\pm\sigma$	7,3	4,1	3,9	4,2	6,7	4,2	6,7	7,7	6,6	8,8
	$\pm m$	3,0	1,7	1,6	1,7	2,7	1,7	2,7	3,1	2,7	3,6

Note: Here and in Table 2, 0 refers to hearing threshold before test.

Table 2. Increase in hearing threshold in the 10th min of respiration of a mixture with CO_2 concentration up to 8% (mean data)

Index	Tested frequencies, Hz									
	125	250	500	1000	2000	3000	4000	6000	8000	10 000
Increase in hearing threshold, dB	23	20	16	15	14	17	21	17	18	22

Qualitatively different reactions of the auditory analyzer were recorded with the use of a gas mixture containing about 8% CO_2. In this case, changes in hearing occur already in the 7th-10th min of exposure, and they are quantitatively substantially different from background indices (Table 2).

We interpret the temporary elevation of hearing thresholds with an inadequate factor, in excess of 15-20 dB, as evidence of the considerably deleterious effect of an altered gas environment on the auditory system. If the above concentrations of CO_2 in inhaled air are exceeded, there could be total loss of hearing efficiency. Such reactions occur against the background of rather significant general changes in reactions of the cardiovascular and respiratory systems, indicative of onset of a decompensation phase [4]. A comparison of the functional state of the acoustic analyzer to the systemic adverse reactions to breathing a gas mixture with CO_2 concentration increased to 8% indicates that the auditory system is quite resistant, and this must be taken into consideration in developing principles regarding display and signal devices when an operatcr has to work under extreme conditions. Analysis of physiological mechanisms that lead to the persistent elevation of hearing thresholds under hypercapnic conditions indicates that preference should be given to central regulation. This is confirmed by the studies of Deccke et al., [7], who demonstrated relative extension of latent reactions of evoked potentials in the region of the auditory zone of the cerebral cortex when subjects breathed gas mixtures with high CO_2 concentration.

BIBLIOGRAPHY

1. Isakov, P. K. VOYENO-MED. ZH. [Military Medical Journal], No 6, 1957, pp 65-68.

2. Korol'kov, V. I.; Savilov, A. A.; and Lunev, I. Ya. KOSMICHESKAYA BIOL. [Space Biology], No 2, 1972, pp 60-64.

3. Krylov, Yu. V. in "Problemy kosmicheskoy biologii" [Problems of Space Biology], Moscow, Vol 7, 1967, pp 327-330.

4. Malkiman, I. I.; Polyakov, V. N.; and Stepanov, V. K. KOSMICHESKAYA BIOL., No 5, 1971, pp 17-22.

5. Petrov, I. R. KLIN. MED. [Clinical Medicine], No 11, 1939, pp 6-9.

6. Popov, A. P. VESTN. OTOLARINGOL. [Vestnik of Otolaryngology], No 2, 1938, pp 152-161.

7. Deccke, L.; Coode, R. C.; Whitehead, J.; et al. AEROSPACE MED., Vol 44, 1973, pp 1106-1111.

10,657
CSO: 1849

END